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PROPOSED REVISIONS TO AERONAUTICAL DESIGN STANDARD – 33E (ADS-33E-PRF) TOWARD ADS-33F-PRF

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14. ABSTRACT
The United States Army's rotorcraft handling qualities performance specification is Aeronautical Design Standard–33 (ADS-33). Since ADS-33E-PRF was published in March 2000, many flight tests and research efforts in the United States and abroad have provided valuable lessons and data to support potential updates. This report describes proposed changes to ADS-33E-PRF toward a new ADS-33F-PRF. A proposed draft ADS-33F-PRF is included in the report Appendix. The changes encompass major new additions/updates and a significant number of minor changes. The major additions/updates, described in some detail herein, include: new yaw-axis bandwidth the attitude quickness boundaries; new side-stick inceptor characteristics; new disturbance rejection criteria; new external slung load criteria; and a new slung load MTE. All of the proposed additions and updates, including a significant number of minor changes, are described in the Changes from Previous Issues section in the draft ADS-33F-PRF.

The existing criteria in ADS-33 are based on current vehicles within the DoD fleet. The FVL family will cover a range of vehicle sizes and speeds not seen before. Continued Army-Navy-NASA S&T research in rotorcraft flight control and handling qualities and government-industry collaboration will be needed to produce the follow-on version of ADS-33 applicable to the FLV family of vehicles.

15. SUBJECT TERMS
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Abstract

The United States Army's rotorcraft handling qualities performance specification is Aeronautical Design Standard–33 (ADS-33). The initial version, ADS-33A, was published in 1987, and applied to the U.S. Army's Light Helicopter Experimental program (LHX), which later evolved into Comanche. ADS-33 has been refined four times; the current version is the "E-version," published in March 2000. Over the last two decades or so, since ADS-33E-PRF was published, many flight tests and research efforts in the United States and abroad have provided valuable lessons and data to support potential updates.

This report describes proposed changes to ADS-33E-PRF toward a new ADS-33F-PRF. A proposed draft ADS-33F-PRF is included as Appendix 1 of this report. The changes encompass major new additions/updates and a significant number minor of changes. The major additions/updates, described in some detail herein, include: new yaw-axis bandwidth and attitude quickness boundaries; new side-stick inceptor characteristics; new disturbance rejection criteria; new external slung load criteria; and a new slung load MTE. All of the proposed additions and updates, including a significant number of minor changes, are described in the Changes from Previous Issues section (paragraph 6.3) in the draft ADS-33F-PRF (Appendix 1).

The existing criteria in ADS-33 are based on current vehicles within the DoD fleet. The FVL family will cover a range of vehicle sizes and speeds not seen before. Continued Army-Navy-NASA S&T research in rotorcraft flight control and handling qualities and government-industry collaboration will be needed to produce the follow-on version of ADS-33 applicable to the FVL family of vehicles.

Introduction

Aeronautical Design Standard–33 (ADS-33) is a United States Army rotorcraft handling qualities performance specification that contains criteria suitable for a range of rotorcraft from Scout and Attack to Utility and Cargo. ADS-33 evolved from an effort to update the 1950's military helicopter flying and ground handling requirements, MIL-H-8501 (Refs. 1 and 2), and the need for new mission-oriented handling qualities requirements for the U.S. Army's Light Helicopter Experimental program (LHX). In 1987, the Army's Aviation Systems Command (AVSCOM) adopted the 8501 Update effort as Aeronautical Design Standard–33 (ADS-33) (Ref. 3). It was distributed with the draft request for proposals for LHX, which later evolved into Comanche.

Since the initial 1987-version, full flight-test evaluations of ADS-33 have been performed using: an AH-64A Apache (Ref. 4), a CH-47D Chinook (Ref. 5), a BO 105 (Ref. 6), a variable-stability Bell 205, a UH-60A Black Hawk (Ref. 7), and a CH-53G (Ref. 8); and partial evaluations using a Puma, AH-1 Cobra, EC-135, MD900, and other rotorcraft (Fig. 1). ADS-33 has been refined four times; the current version is the "E-version," ADS-33E-PRF (Ref. 9). ADS-33 not only provides design guidance, but detailed methods for compliance assessment (Ref. 10) and has been used on national (Refs. 11-18) and international programs (Ref. 19).

Over the last two decades or so, since Aeronautical Design Standard–33E (ADS-33E-PRF) was published in March 2000, many flight tests and research efforts in the United States (e.g., Refs. 20-33) and abroad (Refs. 34-37) have provided valuable lessons and data to support potential updates to ADS-33E. These have included recommendations for text corrections/clarifications, to changes in existing criteria/requirements, as well as new proposed criteria and Mission Task Elements (MTEs). Note that some of the recommendations will require further research to solidify requirements and boundaries. Also, the proposed recommendations are primarily based on legacy helicopters and do not include lessons learned from recent Future Vertical Lift (FVL) configurations, which will need to be included in future updates. Toward these future updates, new high-speed MTEs, applicable to FVL, have recently been developed and proposed (Refs. 38-41). However, the development of these high-speed MTEs, at this point in time, is based entirely on ground-based simulations. Before inclusion in an ADS-33 update, these MTEs need to be flight tested and lessons learned from these tests included in the MTEs.

This report describes proposed changes to ADS-33E-PRF toward a new ADS-33F-PRF. These changes, based on the aforementioned lessons and data, encompass major new additions/updates and a significant number of minor changes. The major additions and updates include: new yaw-axis bandwidth and attitude quickness boundaries (Ref. 42); new side-stick inceptor characteristics (Ref. 32); new disturbance rejection criteria (Ref. 43); new external slung load criteria (Ref. 44); and a new slung load MTE (Ref. 31). The numerous minor changes include corrections to spelling/punctuation errors, revisions to criteria definitions and boundaries, and updates to several MTEs.

The following sections describe the major additions/updates is some detail. Note that the proposed changes have been incorporated into a draft ADS-33 "F-version," which is attached in Appendix 1 of this report. Descriptions of all of the incorporated changes are captured in the Changes from Previous Issues section (paragraph 6.3) in the draft ADS-33F-PRF (Appendix 1).

Yaw Bandwidth and Attitude Quickness

The Predicted handling qualities in ADS-33 are defined in terms of the flight condition and response type, as well as the maneuver category and magnitude. Small amplitude control response characteristics are defined using the Bandwidth criteria. Moderate amplitude requirements are defined by the attitude quickness specification, which effectively defines the transition between the bandwidth and large amplitude (maximum rate) specifications.

The Bandwidth criteria consists of both the bandwidth frequency (ω_{BW}) and the phase delay (τ_p) parameter. The bandwidth frequency is computed using the attitude frequency response, and for a rate-command system is the lesser of the gain bandwidth ($\omega_{BW\ Gain}$) and the phase bandwidth ($\omega_{BW\ Phase}$). The phase bandwidth is the frequency at which the phase curve crosses through -135°, while the gain bandwidth is the frequency at which the magnitude is 6dB higher than at the ω_{180} phase crossing. The phase delay parameter (τ_p), captures the pilot's sensitivities to the shape of the phase curve at frequencies beyond the bandwidth frequency. That is, phase delay is a measure of the steepness with which the phase drops off after -180° and indicates the behavior of the aircraft as the pilot increases his crossover frequency. The ADS-33E-PRF yaw bandwidth boundaries are shown in Figure 2 (a) and (b) for the Target Acquisition and Tracking and All Other MTEs categories respectively.

The attitude quickness specification is a time domain measure of the extent to which the response characteristics degrade at moderate amplitudes (defined as the 10-60° range). Nonlinearities such as actuator rate limiting reduce the effective bandwidth of the system at larger amplitudes, which can in turn lead to handling qualities degradations. The current ADS-33E-PRF attitude quickness boundaries for the Target Acquisition and Tracking and All Other MTEs categories are shown in Figure 3 (a) and (b) respectively.

The supporting data available for use at the time of initial development of the yaw-axis ADS-33 specifications was somewhat limited (Ref. 45). While a combination of simulation and flight data was used for the development of the Level 1 yaw bandwidth boundary, considerable scatter was present in the data and the resulting boundary was taken from an approximate curve fit. For the moderate amplitude (yaw quickness) specification no data was available, and the boundaries were merely transcribed from the roll-axis requirement (Ref. 45). A subsequent Army yaw-axis study (Ref. 46) was undertaken in the NASA-Ames Vertical Motion Simulator (VMS), leading to a relaxation in the ADS-33C yaw attitude quickness boundary for Target Acquisition and Tracking (Ref. 47). The maximum yaw rate and task tolerances differed significantly from the cargo/utility category, and hence a direct translation to the 'All Other MTEs' boundary was not possible.

Since it was first introduced, considerable experience has been gained with ADS-33 across a broad range of aircraft types, providing a flight test database suitable for a comprehensive comparison between analytical and in-flight assessments of yaw axis handling qualities. This testing covered: utility aircraft ~ UH-60A (Ref. 7), UH-60M (Ref. 22), and NH90 (Ref. 19); cargo aircraft ~ CH-53G (Ref. 36), CH-47D/F (Ref. 48); as well as scout/attack aircraft ~ OH-58, AH-64A, Comanche, and BO-105 (Refs. 6 and 49-53).

For these ten aircraft, a comparison was made between: the predicted Handling Qualities Ratings (HQRs) as based on the yaw-axis bandwidth, attitude quickness and large amplitude requirements for each aircraft; versus the assigned HQR results for the Hover Turn MTE. The results indicate that for all but one aircraft (CH-47D) the bandwidth and/or attitude quickness predicted equivalent HQRs exceed the assigned values. While the CH-47D assigned HQR was greater than the designated equivalent values, significant roll-yaw coupling was noted in the test comments, which is likely to have led to a degradation in the assigned HQRs. Overall, these results indicate that there is a mismatch between the predicted and assigned levels, and that a re-examination of both the yaw-axis bandwidth and attitude quickness requirements was warranted.

A comprehensive study (Ref. 42) was performed to examine the underlying principles behind the yaw-axis specifications and the relationships between bandwidth, attitude quickness, time/phase delay, and key input parameters, such as actuator rate limiting. These relationships were subsequently used to establish configurations for flight test and for analysis of flight test and literature data. The analytical modeling results from this study indicated that the Level 1 yaw-axis bandwidth boundary, for All Other MTEs, would need to be significantly reduced from the current ADS-33E-PRF value of 2.0 r/s, to approximately 0.5 r/s. Accompanying reductions to the attitude quickness boundaries were also noted. To flight validate the analytical results, a flight test was planned and conducted on the Aviation Development Directorate–Ames (CCDC AvMC ADD-A) variable-stability research aircraft, the Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL) helicopter, a JUH-60A Black Hawk as shown in Figure 4.

The RASCAL aircraft (Ref. 54) features a full authority fly-by-wire flight control system for the right seat, and maintains the standard UH-60 mechanical controls in the left seat, providing a fail-safe backup system for the safety pilot. Configuration parameters for the research system can be modified in flight by the system operator, located in the rear cabin of the aircraft.

The research system for this test was configured with explicit model following control laws, developed for use in a number of previous CCDC AvMC ADD-A studies (Ref. 55). The control laws featured attitude command velocity hold response types in pitch and roll, with automatic deceleration to position hold below 5 kts groundspeed. The vertical axis provided a vertical speed command response with radar altitude hold when in detent. A rate command direction hold (RCDH) response type was incorporated into the yaw axis.

Yaw-axis parameters in the flight tests were varied by modifying yaw command model parameters in the control laws. A schematic of the yaw command model is shown in Figure 5. The yaw bandwidth and phase delay were varied using the first order time constant ($1/Nr_{cmd}$) and the time delay parameter (τ_{cmd}).

Attitude quickness variations were achieved with the acceleration rate limit parameter ($\dot{r}_{lim}$), and the sensitivity for each configuration was optimized using the pedal sensitivity gain ($K\delta_{ped}$).

The flight test activities were separated into two phases. Phase 1 involved evaluating the Level 1 and 2 bandwidth boundaries, while Phase 2 evaluated the Level 1 attitude quickness boundary. For Phase 1, the test procedure involved varying the bandwidth along a line of constant phase delay, using a linear command model (acceleration rate limit deactivated) and optimizing the sensitivity based on pilot preference, selecting the pedal shaping function as required to maintain a maximum yaw rate of 22°/s. Experimental test pilots evaluated the range of configurations by performing a hover turn and a heading capture maneuver. A 'Modified' Hover Turn MTE was utilized, which was the standard ADS-33E-PRF Hover Turn, with the position and altitude hold requirements removed. The aircraft position and altitude were maintained by the control laws (Ref. 55), making the task effectively a single (yaw) axis maneuver. In addition, to more effectively assess the attitude quickness requirements, a hover Heading Capture maneuver was performed, which consisted of a 30-degree heading change to the right (or left), followed by a stabilized pause for 2-seconds, then a turn back to the initial heading. Cooper-Harper ratings (Ref. 56) were taken for each test point, along with an additional questionnaire of aggressiveness, precision, ride quality and predictability for key points.

Bandwidth evaluations were also conducted using the standard ADS-33E-PRF Hover Turn MTE with position and altitude holds deactivated in the control laws, providing an ACAH response in pitch and roll, and velocity command in the vertical axis. The pilot was required to be in position at the beginning and end of the maneuver, and Cooper-Harper ratings were given for the whole maneuver as well as for the yaw axis only.

The attitude quickness evaluations for Phase 2 involved progressively reducing the acceleration rate limit value in the command model, simulating an actuator rate limit. This produced a series of systems with constant bandwidth and varying attitude quickness. A linear system placed just inside the Level 1 bandwidth boundary (as determined from Phase 1) was utilized, and the quickness was reduced until Level 2 qualitative ratings were received. The 30° Heading Capture maneuver was employed, with a maneuver completion time of 10 seconds for desired performance. The maneuvers were conducted at the CCDC AvMC ADD-A ADS-33 course at Moffett Field, CA.

Qualitative assessments were completed for the bandwidth evaluations using three pilots. Handling qualities ratings for the modified hover turn task are presented in Figure 6. The error bars in the figure represent the range of pilot ratings. Assigned HQRs were consistently Level 1 above a bandwidth of 0.6 rad/sec, with the exception of the highest tested value of 1.8 rad/sec. Pilot comments indicated that the high bandwidth configurations exhibited “jerky” ride characteristics and that ride quality was the primary factor in the ratings, as is discussed in the following section. Below 0.6 rad/sec, the HQRs increased approximately linearly with reducing bandwidth, receiving an average HQR of 5.1 at a bandwidth of 0.236 rad/sec. A regression fit through the HQR results is shown with the red line, which suggests that Level 1 ratings are attainable for a bandwidth of 0.5 rad/sec or greater.

A limited number of bandwidth evaluations were performed using the heading capture maneuver in order to investigate the consistency between the two. The heading capture results are indicated by the green crosses on the figure, and demonstrate the same general trends as for the hover turn. Above a bandwidth of 0.5 rad/sec the heading capture was rated Level 1 (HQR 3), while at a bandwidth of 0.45 rad/sec was rated Level 2 at HQR 4.5. Based on these results, it was concluded that the two maneuvers could be used interchangeably for qualitative evaluations.

The flight test results were based on the ‘All Other MTEs’ category, and culminated in a set of boundaries based on the Hover Turn and Heading Capture maneuvers. This data was then combined with ADS-33 test data extracted from public domain literature (Refs. 6, 7, 19, 22, 36, and 48-53) to propose updates to the yaw-axis boundaries in ADS-33F. The qualitative evaluations in the literature data are based on the Hover Turn MTE. Shown in Figure 7 are the proposed ADS-33F bandwidth/phase delay boundaries using the RASCAL flight test and literature data. The RASCAL flight test data is colored according to average hover turn HQRs, and the solid points represent Level 1 HQRs. The literature data is labelled by aircraft and hover turn HQR, and colored using the same regime as the RASCAL data. The current ADS-33E boundaries are shown in light grey, while the proposed boundaries are in black.

The proposed yaw-axis bandwidth boundaries are significantly lower than the current ADS-33E boundaries, with the proposed Level 1 boundary being very close to the current Level 2 requirement. The RASCAL flight test data agrees well with the proposed Level 1 boundary, with HQR 4 and 5 ratings placed consistently on the left-hand side of the boundary.

The same comparison between flight test and literature data is presented in Figure 8 for attitude quickness. The current ADS-33E boundaries are shown in light grey, and the proposed boundaries are shown with black solid lines. Attitude quickness curves corresponding to points from the regression fit of HQR as a function of effective Nr are shown with broken lines, representing the RASCAL flight test HQRs (for the Heading Capture maneuver). The literature attitude quickness points are plotted and labelled according to aircraft and hover turn HQR. As with the previous figure, points/lines are colored according to assigned HQR value. The proposed attitude quickness boundaries represent a considerable reduction from the ADS-33E values, as was the case for the bandwidth boundaries.

Side-Stick Inceptor Characteristics

The mechanical controller characteristics requirements are addressed in section 3.6 of ADS-33E-PRF. Paragraph 3.6.1 applies to conventional controllers (center-stick cyclic, pedals and left-hand collective) whereas, paragraph 3.6.2 is reserved for side-stick controllers. Paragraph 3.6.2 is currently empty because at the time ADS-33E-PRF was written there simply was not enough quantitative or even qualitative data to set requirements for side-stick controllers. The remaining paragraphs, 3.6.3 through 3.6.7, address sensitivity and gradients, cockpit control free play, control harmony, trimming characteristics and dynamic coupling respectively. The requirements presented in section 3.6 are based on requirements in MIL-H-8501A (1961) (Ref. 2) and MIL-F-83300 (1970) (Ref. 56), with adjustments based on a review of some controller characteristics of helicopters in operational use by the Army at the time (late 1990s). During this era, Army helicopters were almost exclusively rate command (RC) aircraft with control systems where the force-feel characteristics are determined by mechanical components such as springs, dampers and servos, with perhaps a trim release to minimize trim system forces when disengaged. To change force-feel characteristics of these systems requires the change of a mechanical component. The intent of the requirements in section 3.6 is to provide guidance on the range of force/deflection gradient, breakout force including friction, which should assure good control characteristics for conventionally controlled rotorcraft.

Currently the CH-53K being developed by Sikorsky for the Navy will be fly-by-wire with active side-stick controllers (Ref. 58), and the Joint Multi Role Technology Demonstrators will have fly-by-wire control systems, which will support active cyclic inceptors. This type of inceptor allows the force-feel characteristics to be determined by the closed-loop response of the active inceptor itself as defined by the inertia, force/displacement gradient, damping, breakout force and detent shape configuration parameters in the inceptor control laws. Figure 9 shows the measured lateral force displacement plot for two aircraft, a UH-60A with a standard mechanical flight control system, and from the RASCAL fly-by-wire JUH-60A with an active center stick cyclic (Refs. 20, 32). The hashed lines on the plot indicate the current ADS-33E Level 1 hover and low speed boundaries from section 3.6.1. The UH-60A mechanical force displacement curve exceeds the Level 1 boundaries, exhibits variations in the force-displacement gradient depending on the displacement from trim and the direction of travel, and has an average friction band of about 2 lb. The active inceptor force-displacement gradient is well within the boundaries, and is linear independent of displacement or direction and has almost no friction band. These inceptors are not only easy to configure, but also allow the freedom to vary the force-feel characteristics for different command response types and different flight conditions. A number of studies have been conducted to assess the impact of controller force-feel characteristics on the pilot-vehicle flying qualities, some specifically addressing rotorcraft (Refs. 32, 37, 59-67). Of particular interest are five of the most recent studies, two conducted on simulators with side sticks (Refs. 37, 58) and three conducted in-flight with both center-stick and side-stick cyclic controllers (Refs. 32, 66, 67). A summary of the findings from these studies follows.

In general, all of the studies concluded that the cyclic inceptor force-feel characteristics can have a significant impact on the overall handling qualities; this was observed both in simulation and flight. The fixed-based study of Reference 58 found that side stick inceptor travel should be in the range of ± 0.8 to ± 1.4 inches, which agrees with results of the fixed-based study of Reference 37 that found that the optimal side stick inceptor travel is about ±1 inch. This range provided a good tradeoff of large enough travel to allow the pilot sufficient precision to perform tasks that required precise control without causing excessive fatigue or the perception of decreased aircraft bandwidth. Pilot control forces must be set for the inceptor type and for the command response type. For a center sticks, symmetric forces for pitch and roll work well, whereas for side sticks symmetric pitch forces and asymmetric roll forces were preferred (Refs. 32, 58, 66, 67). The asymmetric roll forces used in the studies of Reference 66 were adopted because with a side stick sustaining roll forces to the right are more fatiguing than sustaining roll forces to the left. The overall pilot control forces were a factor, especially for attitude command (AC) response types due to the sustained stick displacements required for maneuvering flight (Ref. 58). This limits the maximum force-displacement gradient that can be used for attitude command in order to minimize pilot fatigue. These parameters along with the inertia of the inceptor determine the natural frequency of the inceptor, which has been shown to be an important factor that impacts handling qualities.

When comparing simulation and flight, it was observed that motion cues can have an impact on the perceived optimal cyclic force-feel configuration. The study of Reference 37 identified an optimal set of side-stick force feel characteristics using a high-fidelity fixed-based simulation of the ACT/FHS EC-135 helicopter operated by DLR. While the simulation results generally agreed with flight test results, for both rate command and attitude command, the fixed-based study tended to under predict the damping required to obtain optimal handling qualities. This was attributed to the lack of vestibular feedback in the simulator (Refs. 37, 66, 67). Three flight studies identified optimal cyclic force-feel configurations with damping ratios greater than one (Refs. 32, 66, 67). In References 66 and 67, it was observed that these over-damped second-order systems can be represented as two first-order systems, where the first-order system with the smaller time constant can be reduced to a pure time delay. The author of Reference 67 proposed that the delay should be minimized to the greatest extent possible leaving only the time constant to be set to obtain optimal handling qualities. Figure 10 shows the mapping from damping and natural frequency for a second-order system onto the equivalent time constant and time delay space of two first-order systems; the solid lines are lines of constant damping and the dashed lines are lines of constant natural frequency. The best configurations identified from the flight testing with a center stick from Reference 32 (Hover and Slalom MTEs, attitude command), from flight testing with a side stick from Reference 67 (roll tracking task, attitude command), and from simulation testing with a side stick of Reference 37 (Hover MTE, attitude command) are shown on the plot. It is recognized in Reference 67 that the physical limitations of the inceptor hardware limit the minimum achievable time delay.

Application of Bandwidth Criteria to Flight Data

The short-term response to control inputs (bandwidth) for small-amplitude pitch and roll attitude changes are defined in ADS-33E-PRF section 3.3.2. This requirement states that pitch (roll) response to the longitudinal (lateral) cyclic control position inputs shall meet the specified limits. It also states that it is desirable to also meet the criteria for controller force inputs. The bandwidths from both displacement and force were calculated for the configurations evaluated during the study investigating the interaction between inceptor force-feel characteristics and handling qualities of Reference 32. The roll bandwidths for Attitude Command (AC) are plotted in Figure 11a, and the pitch bandwidths for AC are plotted in Figure 11b with the specified limits for UCE = 1 and fully attended operations. The roll bandwidths for RC are plotted in Figure 12a, and the pitch bandwidths for Rate Command (RC) are plotted in Figure 12b with the same limits. The numbers in brackets are the average HQRs from the Hover MTE for each center-stick configuration. The differences between the two displacement points on the plots are due to the location of the control position measurement. The displacement inputs for the CLAW are at the input to the control laws, where the inceptor inputs are the unfiltered outputs of the cyclic inceptor rotary potentiometers. The differences between the two are primarily due to anti-alias filters on the inceptor signals.

All of the bandwidths and phase delays from the position inputs are solidly in the Level 1 regions of the criteria, although there is a significant loss of bandwidth and increase in phase delay due to the anti-alias filters. All of the plots suggest that configuration C would confer the best ratings as the C inceptor characteristics impart the least reduction in the bandwidth, and the least amount of additional delay. This prediction does not agree with the HQRs from the Hover MTE which show that configuration B confers the best HQRs. These results show that all of the force points that fall in the Level 2 region received Level 2 HQRs, however all the force points in the Level 1 region did not receive Level 1 HQRs. This result indicates that the bandwidth/phase delay criteria should be *evaluated using displacement inputs*, and the force-feel characteristics should be considered separately.

Disturbance Response

ADS-33 Criteria

Two existing ADS-33 criteria address the disturbance response. The first criteria, the "Character of Attitude Hold and Head Hold Response-Types" (ADS-33E-PRF, paragraph 3.2.7), evaluates the time response following an un-commanded input. This criteria requires that the pitch attitude response following a pulse (disturbance) input to the control actuator return to within 10% of the peak value or one degree (whichever is greater) within:

- 20 seconds for UCE=1
- 10 seconds for UCE>1

The roll attitude and heading response shall return to within 10% of the peak value or one degree in less than 10 seconds. The criteria is limited because it focuses on the steady state and neglects the short-term speed of the recovery immediately follow the disturbance.

The second criteria, the "Short-term pitch and roll responses to disturbance inputs" (ADS-33E-PRF, paragraphs 3.3.2.2, 3.3.7 and 3.4.11) examines the bandwidth frequency for inputs directly into the control actuator. The intent of this disturbance input criteria is to ensure that the required control response bandwidth is not achieved with forward-loop shaping, thus neglecting the potential benefits for disturbance rejection associated with feedback. However, extensive experience in the past few years indicates that this ADS-33 requirement is easily met even for little or no attitude feedback and does not properly evaluate or drive the design to achieve satisfactory gust rejection. To address these shortcomings in the existing ADS-33 criteria, a new specification has been developed and applied in numerous recent flight control design and flight test programs.

CCDC AvMC ADD-A Disturbance Rejection Criteria

CCDC AvMC ADD-A has developed and validated a new frequency-domain disturbance rejection criteria (Ref. 10). This disturbance rejection criteria is based on frequency-domain analysis of the attitude response to a disturbance sweep added to the measured hold response variable. For example, the *attitude disturbance response* is characterized by the frequency response ϕ/ϕ_d shown in Figure 13.

There are two requirements based on this disturbance frequency response: Disturbance Rejection Bandwidth (DRB) and Disturbance Rejection Peak (DRP) magnitude. Figure 14 illustrates how these metrics are defined from the magnitude response.

The disturbance rejection bandwidth (DRB) characterizes the speed of response recovery from a disturbance, or how quickly the disturbed hold response will return to trim. For an attitude hold system, the DRB is defined as the frequency where the disturbance response ϕ/ϕ_d crosses the -3dB point as indicated by Eq. (1).

$$\phi/\phi_d = -3\,\mathrm{dB} \equiv \mathrm{DRB\ (rad/s)} \qquad (1)$$

In a flight test case where the there are multiple crossing of the -3 dB point, the lowest frequency is taken as the DRB frequency. The disturbance rejection bandwidth is directly analogous to the pilot response bandwidth, except that the excitation is now at the output. Experience has shown that a feedback system with adequate disturbance rejection bandwidth is recognized by the pilot as having good “trimmability,” (Ref. 14) because the aircraft will hold the desired trim state in the presence of disturbances and not require continuous re-trimming.

The disturbance rejection peak (DRP) characterizes overshoot in the initial response and is defined as the maximum magnitude on the disturbance rejection Bode plot as indicated by Eq. (2).

$$max\,[\phi/\phi_d] \equiv \mathrm{DRP\ (dB)} \qquad (2)$$

As an example of how the disturbance rejection bandwidth specification correlates to disturbance rejection in the time domain, three control systems were compared in a UH-60 simulation with increasing disturbance rejection bandwidths. The disturbance rejection bandwidths of the three systems are shown in Figure 15. The associated ADS-33E-PRF requirement 3.2.7 for evaluating the “disturbance” impulse at the actuator is shown in Figure 16. As shown, all three systems meet the Level 1 requirement of returning to within 10% of the peak within 10 seconds. However, the three systems clearly have different disturbance characteristics, as shown in the time and frequency domain. In the time domain, the dashed-line design rejects the disturbance in less time (though more oscillatory), which is consistent with the higher DRB but increased DRP in the frequency domain. This trade-off, which is well known in the classical literature (Ref. 68), is sometimes termed the “water bed effect.”

The ADS-33 time domain specification cannot capture the differences in these responses; it only indicates that they all meet the required return to steady state trim within 10 seconds. The disturbance rejection bandwidth specification better characterizes the short-term disturbance response, whereas the current ADS-33 3.2.7 specification well captures the long-term response. Thus, the time domain specification proves useful for tuning of integrators to eliminate drift in the steady-state response. This has also been particularly helpful in minimizing off-axes drift (Ref. 20).

These new disturbance rejection criteria have been a useful basis for flight control design on many recent programs, including: CH-47F (Ref. 14), ARH (Ref. 27), unmanned RQ-8B (Ref. 69), AH-64 MCLAWS (Ref. 70), unmanned K-MAX (Ref. 71), and the UH-60 (Refs. 33, 72, 73). Published results from these programs validate that the DRB is a key design metric and an excellent characterization of "trimmability" and disturbance rejection "tightness." Suggested values for Level 1 pitch, roll, and yaw attitude disturbance rejection bandwidth criteria were initially published in the ADS-33 Test Guide (Ref. 10) (note that there was a typo in the initial release of the Test Guide that showed an incorrect pitch requirement of DRB ≥ 0.9 rad/sec; the correct value is shown in Table 1). These values were developed based on simulation and flight testing of the UH-60, as well as experience on other rotorcraft programs mentioned previously.

A compilation of published inner (attitude) loop DRB data is shown in Figure 17a, b, c for the pitch, roll, and yaw axes respectively. Also shown are the attitude DRB boundaries from Table 1. Particularly interesting is the correlation of the pitch and roll data for the UH-60 without and with moderate turbulence in the GVE. All of the ADS-33 boundaries are *minimum values* and handling-qualities validation based on the associated MTEs is conducted in no turbulence. We notice that in Figure 17a the UH-60 flight control system represented by the triangle symbol (2009 data, Ref. 73) well meets suggested pitch DRB criteria value and confers Level 1 handling-qualities in no turbulence. When the DRB is reduced to just below the criteria in the circle symbol (2013 data, Ref. 33), the Level 1 HQR are maintained for no turbulence, as expected for the *minimum values* as recommended by ADS-33. But, when the same system is exposed to moderate turbulence, the handling-qualities just cross the boundary into Level 2 (HQR=4). By increasing the DRB to a value in the square symbol (2013 data, Ref. 33), the control system confers Level 1 ratings in both no turbulence and moderate turbulence conditions. This indicates that the location of the minimum DRB boundary is nicely validated (perhaps slightly lenient). The same DRB boundary validation is seen in the roll and yaw data correlation of Fig 17b, c, respectively. Increased DRB boundary values are suggested for the DVE conditions, as indicated by the OH-58D data in the diamond symbol, though the lack of a position hold capability might also have compromised the handling-qualities in the DVE. Also, data from Reference 72 would suggest an increased DRB boundary for larger rotorcraft.

DRP criteria values were not provided in the initial test guide, but have been developed since in several programs. Extensive recent experience with the RASCAL JUH-60A (Ref. 34) has validated the DRP requirements and has also provided recommended criteria for the outer velocity and position loops, as summarized in Table 1.

Specification Testing Method

The test procedure injects an automated frequency sweep (Ref. 74) into the measured hold response. The attitude hold DRB test adds the sweep to the measured attitude. For the velocity DRB test, the sweep is added to the measured velocity, and analogously the position DRB test adds the sweep to the measured position. Flight data for a roll attitude DRB are shown in Figure

18. These data are from the RASCAL JUH-60A helicopter with an optimized attitude-command/attitude-hold flight control system (Ref. 73). As can be seen, the aircraft motions are symmetric and relatively small (compared to piloted sweeps). The resulting disturbance rejection response is identified with excellent coherence, as seen in Figure 19. The roll DRB value extracted from this response, as also shown in the figure, meets the proposed Level 1 criteria (in Table 1) as confirmed by the piloted handling-qualities evaluation. Recent RASCAL flight test results for yaw DRB/DRP are shown in Figure 20 and meets the proposed criteria as also confirmed by an extensive piloted handling-qualities tests that were focused on comparing feedback design strategies (Ref. 33).

External Load Handling Qualities Criteria for Hover and Low-Speed Operations

The dynamic motions of external loads are known to have a significant impact on the handling qualities of helicopter/external load systems during hover/low-speed operations. This was recognized by the inclusion of specific external slung load MTEs in ADS-33D-PRF (Ref. 75). These may cover the qualitative assessment of external load handling qualities, but currently there are still no external load quantitative requirements in ADS-33E-PRF.

Slung Load Criteria ~ Quantitative:

Since the early 1990s, several handling qualities simulation experiments have been conducted in the NASA-Ames Vertical Motion Simulator (VMS) to gather data for expanding the handling qualities specifications for cargo helicopters with external loads. One of the more recent simulation studies conducted in the VMS for the Navy is of particular interest (Ref. 76). The focus of this was on the development of hover and low-speed handling qualities requirements for very large cargo helicopters carrying external sling loads. The study used a CH-53-like helicopter with a gross weight of 80,000 lbs, and evaluated Load Mass Ratios (LMR, the ratio of the mass of the load to the mass of the helicopter plus load) between 0.2 and 0.6 and sling lengths between 30 ft and 70 ft.

The criteria that were developed in Reference 76 are based on the lowest -180 degree crossing frequency versus the attitude bandwidth frequency for the respective axes. This criteria was applied to flight test data in Reference 26, which showed that the criteria did not reliably differentiate between Level 1 and Level 2 handling qualities. It should be noted that the LMRs for the flight data only go up to LMR ~ 0.3, which is on the low end of the LMR range for which the criteria were developed.

Δ_{dB} , Load Bandwidth Hover and Low-Speed Handling Qualities Criteria

In Reference 26, a criterion developed from flight test data was proposed based on a Δ_{dB} parameter and a load bandwidth parameter. These parameters are identified from the pitch and roll closed-loop attitude frequency responses of the externally-loaded aircraft and the attitude frequency response of the test aircraft without an external load but internally ballasted to the same gross weight as the test aircraft plus the external load. The criteria based on these paramaters has been shown to correlate well with the piloted handling qualities ratings. The Δ_{dB} parameter is the deformation of the magnitude curve due to the load, and the load bandwidth ($\omega_{BW\text{-}LD}$) parameter is defined as the lesser of the -135 degree decreasing phase crossing or the minimum phase due to the load mode. Figures 21a and 21b show how the parameters are obtained from the roll and pitch attitude frequency responses respectively. The dashed blue lines in these plots are the attitude frequency responses for a LMR = 0.25, a sling length of 51 ft and a rate command response type. The solid line is the attitude frequency response for the aircraft without an external load but loaded internally to the same gross weight. For the roll case, the depth of the notch in the magnitude curve due to the load relative to the baseline case is Δ_{dB} = 21.6 dB. This parameter is much larger than the parameter from the pitch axes where Δ_{dB} = 14.5 dB. This difference is due to the differences in the aircraft inertias between the roll and pitch axes, and is an indicator that this external-load configuration should have a greater impact on the lateral handling qualities than on the longitudinal handling qualities. It can be seen in Figure 21b that the pitch phase curve just contacts -135 degrees at the load mode. If the phase curve did not quite contact -135 degrees, a criteria that relyed solely on a -135 degree crossing would not capture the frequency at which the external load interacts with the aircraft. This is the reason why the minimum phase due to the load mode is used in the current criteria development when there is not a -135 degree crossing of the phase curve due to the load mode.

The figures also show the centroid of the area between the frequency responses marked as a red circle. The centroid paramater has been developed as an alternative parameter to chatacterize the deformation of the magnitude curve due to the load. This parameter is less sensitive than the Δ_{dB} parameter to the inherent modeling uncertianties associated with frequency domain identification of lightly damped modes where the depth of the notch can vary greatly based on record length and the choice of windows. The centroid parameter is calculated based on the area between the two frequency responses bounded to be no more than ±0.2 radians per second from the load mode frequency. Once the outline of the area is identified, the centroid is calculated from the first moment of area divided by the total area.

$$centroid = \frac{\sum_{i=1}^{n} y_i * dA_i}{A_{total}}$$

Figure 22a and 22b show the criteria plots from Reference 26 updated to reflect a relative HQR rating instead of an absolute HQR rating, and with the boundaries updated to use Δ_{dB} based on the centroid parameter. In the updated criteria, the boundaries are now the same for pitch and roll, but the calculation of Δ_{dB} is different for pitch and roll. Using the centroid paramater, for rate command pitch Δ_{dB} = 4*centroid and roll Δ_{dB} = 3*centroid. To determine the degradation in handling qualties due to the load, the parameters obtained from the closed attitude frequency responses are plotted on the criteria. If they fall to the right, or below the dashed line, the handling qualities degradation due to the external load are expected to be less than one HQR. However, if they fall to the left or above the dashed line, the degradation in handling qualities ratings would be expected to be greater than one HQR. This delta HQR would be added to the expected HQR for the baseline aircraft, which is defined as the aircraft without an external load but internally ballasted to the same gross weight as the aircraft plus the weight of the external load.

Additional data has been collected on the RASCAL JUH-60A to extend the criteria to attitude command response types following the same approach described in Reference 26. The attitude command control laws that were used are described in Reference 31. For this study, the altitude hold, position hold and velocity hold modes were disabled to provide handling qualities ratings for an attitude command response type that has a comparable level of augmentation to the rate command handling qualities ratings collected in Reference 26. The control law gains for this study were updated to provide one gain-set that provided acceptable stability margins for the entire test matrix of sling lengths and load weights to be flight tested (Ref. 31). Lateral and longitudinal piloted frequency sweeps of a subset of the test configurations were collected and used to validate the linear model for use in the quantitative analysis as was done in Reference 26.

Figures 23a and 23b show the centroid based Δ_{dB} and the load bandwidth parameter obtained from the attitude command roll and pitch attitude frequency responses using the same approach as was used for the rate command attitude frequency responses. For attitude command, the criteria boundaries are the same as for rate command, but for attitude command pitch Δ_{dB} = 3*centroid, and roll Δ_{dB} = 3*centroid. Figures 24a and 24b show the paramaters obtained from testing with attitude command plotted on the criteria.

Slung Load Criteria ~ Qualitative:

During the assessment of ADS-33C with a CH-47D (Ref. 5), six external load operations tasks were developed specifically for the Cargo class rotorcraft. These included the Hover, Lateral Reposition, Normal Departure/Abort, and the Vertical Maneuver with an external slung load. These were adopted in ADS-33 updates. Also during the CH-47D flight tests, two other slung load MTEs were developed: Hover Over Load; and Cruise With Load. Both of these MTEs were not adopted into ADS-33 updates. The Hover Over Load MTE (with tighter tolerances than the Hover MTE and with the crew chief providing directions, but with no external load attached to the aircraft) did not provide differences from the basic Hover MTE. The Cruise With Load MTE was found to be straightforward, not very complex, and testing with a dense load did not reveal appreciable problems related to external load dynamics or aircraft-to-load interaction. During the cable-angle feedback research by Ivler (Ref. 31), a *Load Placement MTE* was developed to address the need for a task in ADS-33 that focuses on load motions and load operations. For example, with a long sling and 1,000-lb load, the Lateral Reposition maneuver for the UH-60 (LMR ~0.06) often causes the load to swing at an amplitude greater than 30 degrees and is nearly undamped. This swinging does not significantly affect the HQR for the conventional aircraft repositioning MTEs because the load is relatively light compared to the aircraft and thus does not greatly distort the response to pilot inputs for this task. The newly developed Load Placement MTE addresses the motion of the load and how that affects the handling qualities while delivering a lightly damped load to a precise location on the ground within a finite time. This MTE proved to be a very good discriminator of good and poor configurations for precision load placement during Reference 31 flight tests. The Load Placement MTE is described in the bullets below (in the standard ADS-33 format) and in more detail in Reference 31:

- **Objectives.** The objectives of the load placement MTE are to check the ability to translate with, stabilize, and set down an external load at a specific location, within a reasonable time limit. In addition, this task checks the ability to set the load down without any residual motion of the load on the ground, such as dragging or swinging.

- **Description of Maneuver.** Initiate the maneuver at a ground speed between 6 and 10 knots, with a load clearance of 20 feet above ground level. The load placement target shall be oriented approximately 45 degrees relative to the heading of the rotorcraft. The load placement target is a ground-referenced point, from which the deviation in the set-down point is measured. The ground track should be such that the rotorcraft will arrive over the target point (see Figure 25). Once the aircraft is stabilized in a hover over the load placement target, the crew chief will provide verbal instructions to assist the pilot in placing the load. These instructions should follow the form of *direction-count-hold* as in “Right, 3-2-1, hold” or “Down, 3-2-1, hold” to position the load and set it down.

- **Description of the Test Course.** The suggested test course for this maneuver is shown in Figure 25. Note that the desired and adequate boxes refer to the load set-down point, not the helicopter position during the maneuver.
- **Performance Standards.** Accomplish the transition to hover in one smooth maneuver. It is not acceptable to accomplish most of the deceleration well before the load target point and then creep up to the final position. The load swing should be contained within the desired boundaries (or adequate if trying for adequate performance) before placing the load on the ground. The load should not perceptibly drift, swing, or drag after initial ground contact. All other performance standards are given in Table 2.

Summary

Aeronautical Design Standard–33 (ADS-33) is an innovative mission-oriented handling quality specification. It includes a methodology to account for the effects of Degraded Visual Environment (DVE) in the tradeoff between control response type and pilot's Usable Cue Environment (UCE) to maintain Level 1 handling qualities. ADS-33 contains both quantitative and qualitative criteria. The usage of ADS-33E-PRF, from its publication in 21 March 2000 until now, has provided valuable additions to rotorcraft development efforts, both in the design and assessment. Through this usage and continued research within the United States and internationally, there have been noted corrections and clarifications that have been identified for inclusion in an update. Some of these recommendations will require further research to solidify requirements and boundaries, but many were ready for inclusion. This report describes a few of the significant changes to requirements and boundaries, including: new yaw-axis bandwidth the attitude quickness boundaries; new side-stick inceptor characteristics; new disturbance rejection criteria; new external slung load criteria; and a new slung load MTE.

Appendix 1 contains a proposed draft ADS-33F-PRF. Based on lessons learned and and aforementioned research, numerous changes were incorporated. Descriptions of ALL of the incorporated changes are captured in the Changes from Previous Issues section (paragraph 6.3) in the attached draft ADS-33F-PRF.

The Future

Although sufficient data and lessons learned exist for an update to ADS-33E-PRF, this does not mean rotorcraft handling quality research for database/criteria development is complete. The existing database used for criteria development in ADS-33 is based on current vehicles in the fleet, which are mainly comprised of 1960-80s development technology. These aircraft are aging. It is recognized that upgrades to the current fleet will not provide the capabilities required, and hence a Future Vertical Lift (FVL) family of vehicles is envisioned (Ref. 77). This FVL-family includes multiple sizes and classes of vehicles, considers the vertical lift needs across the DoD, achieves significant commonality between platforms, and addresses the identified capability gaps. The FVL family will cover not only a range of vehicle sizes but speeds not seen before. During the JMR-TD phase, the handling quality database needs to be extended to cover this class of vehicle in preparation for the FVL program-of-record. Continued Army-Navy-NASA S&T research in flight control and handling qualities and government-industry collaboration will be needed to produce the follow-on version of ADS-33 applicable to FVL.

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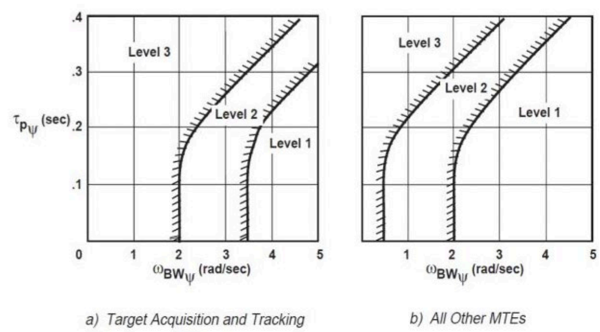

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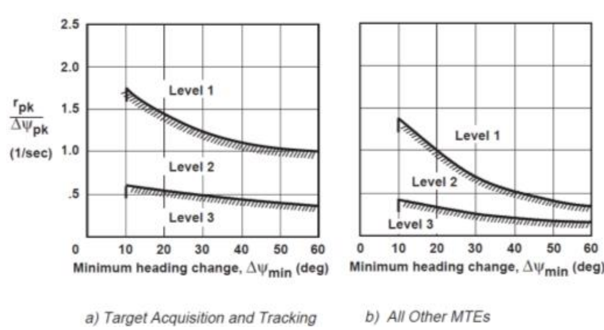

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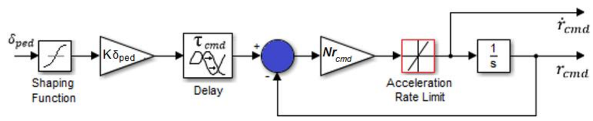

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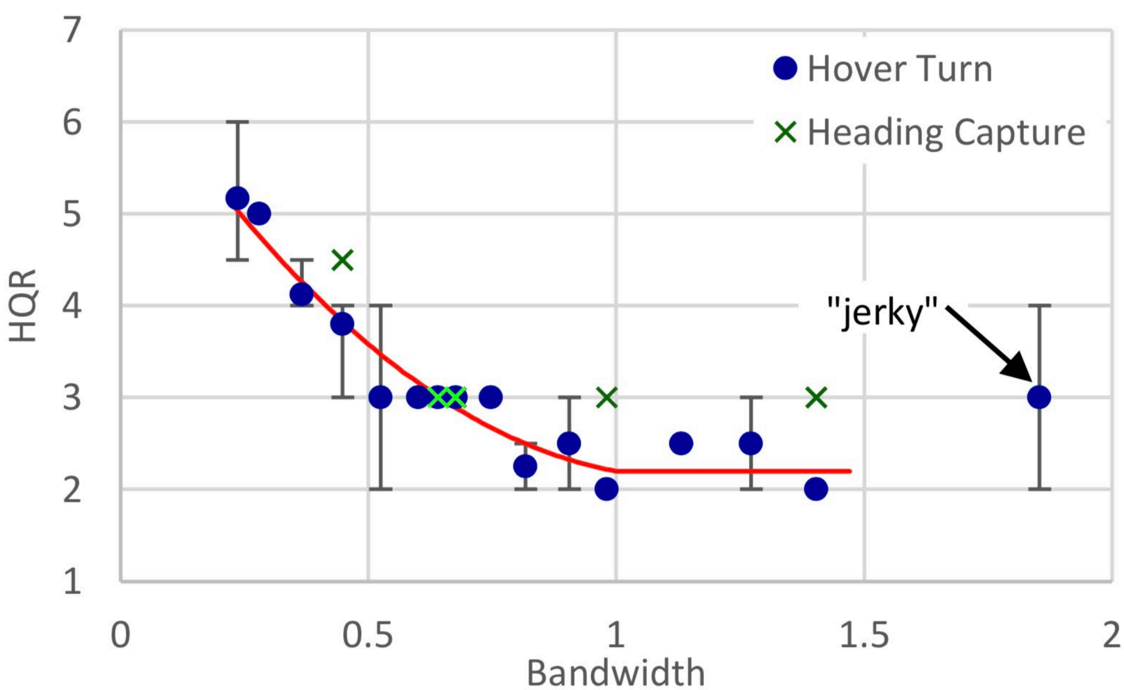

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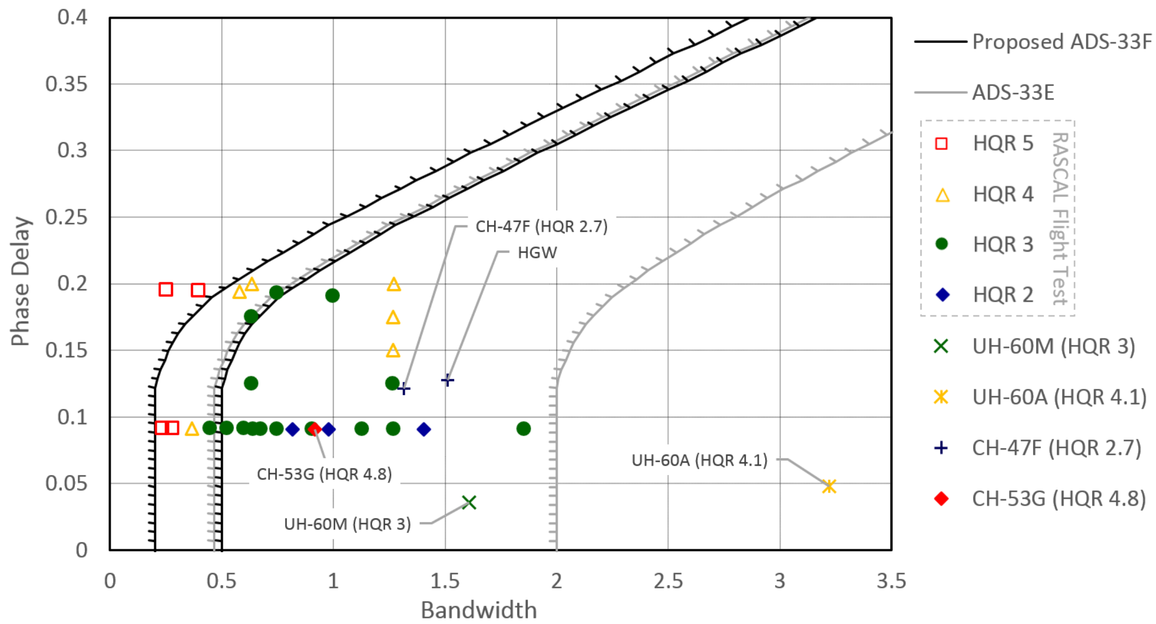

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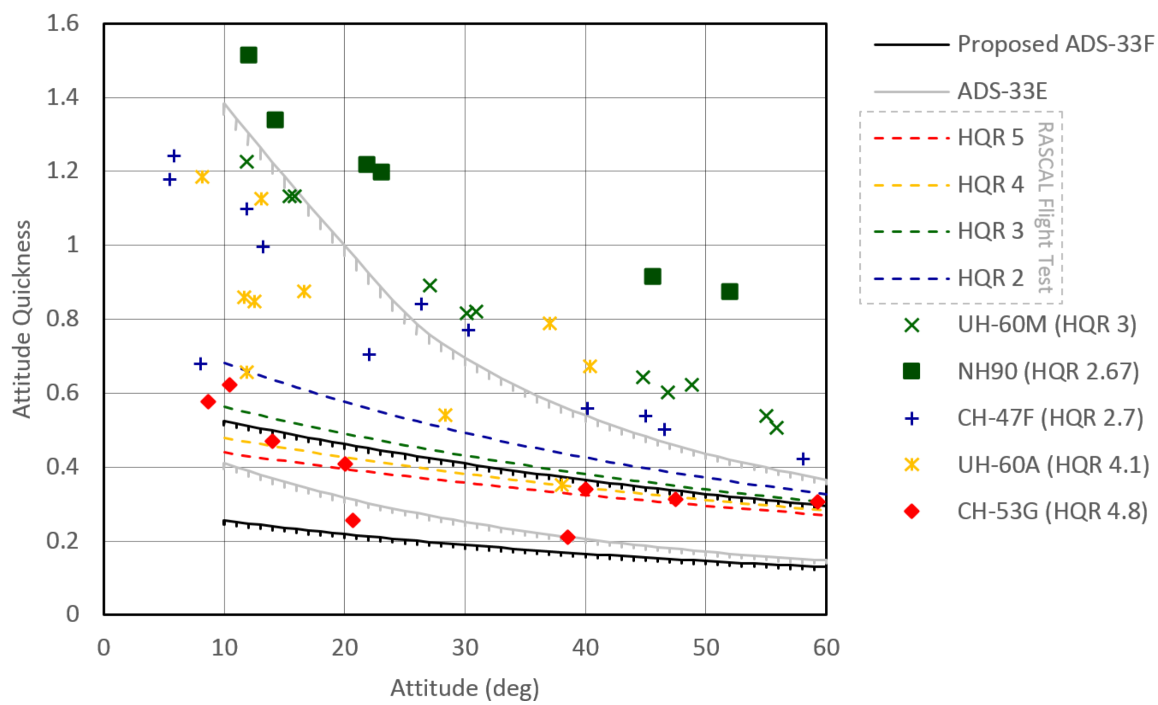

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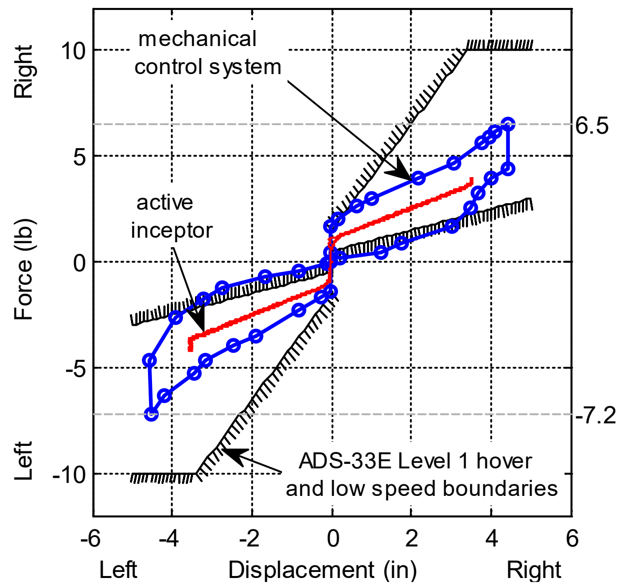

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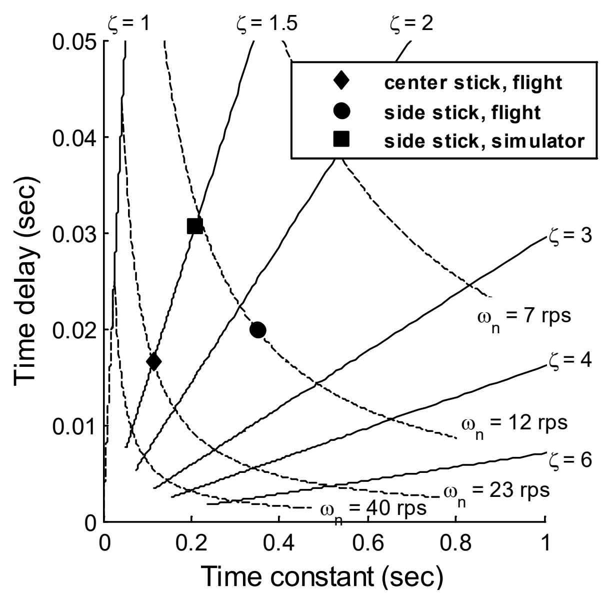

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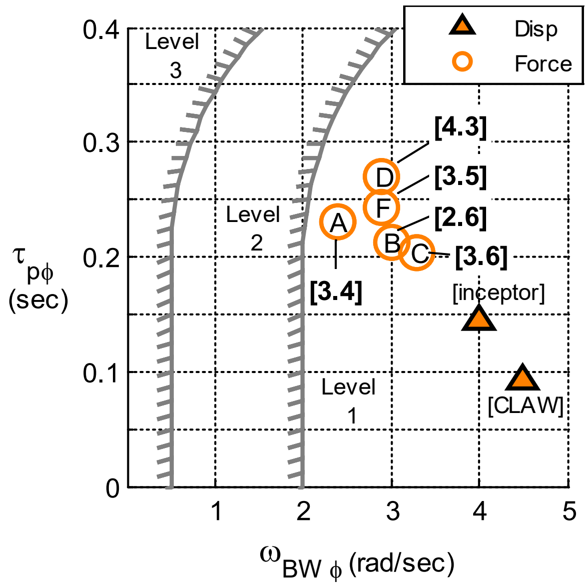

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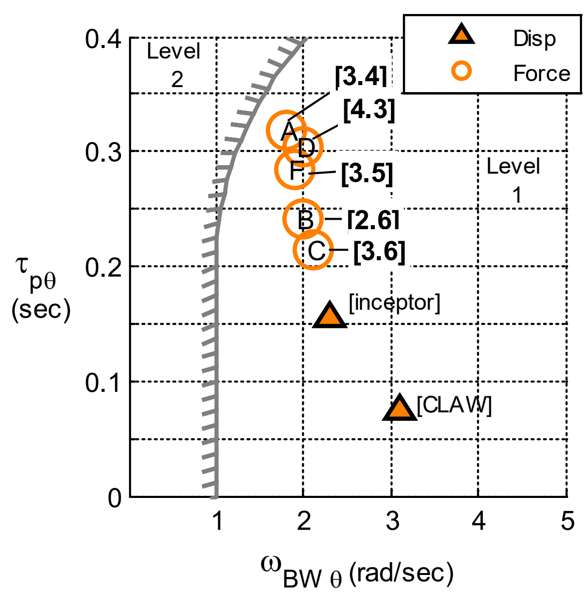

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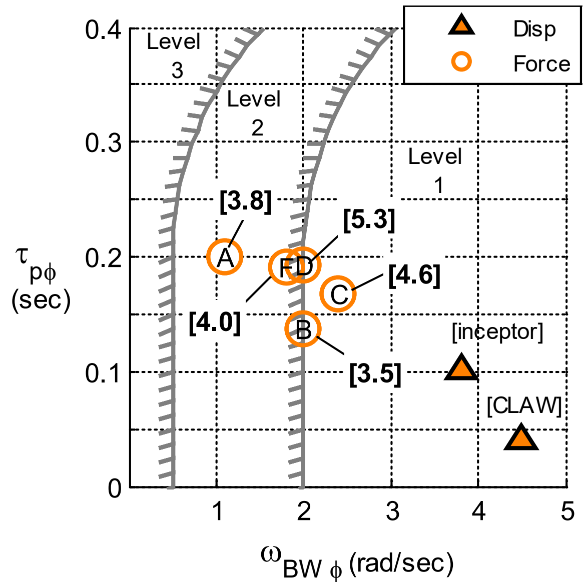

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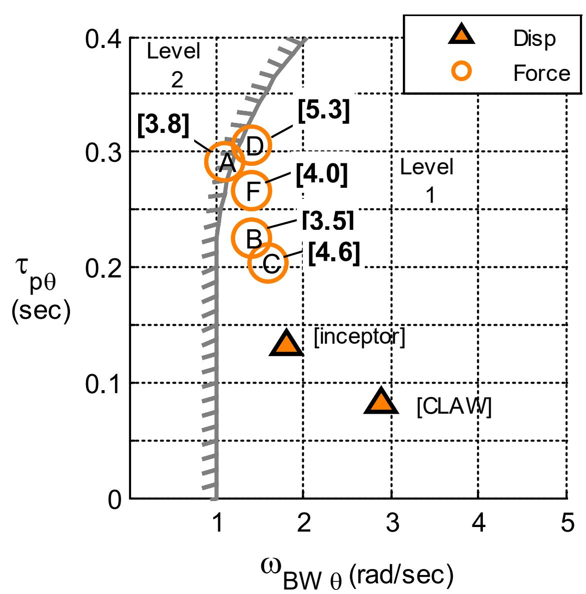

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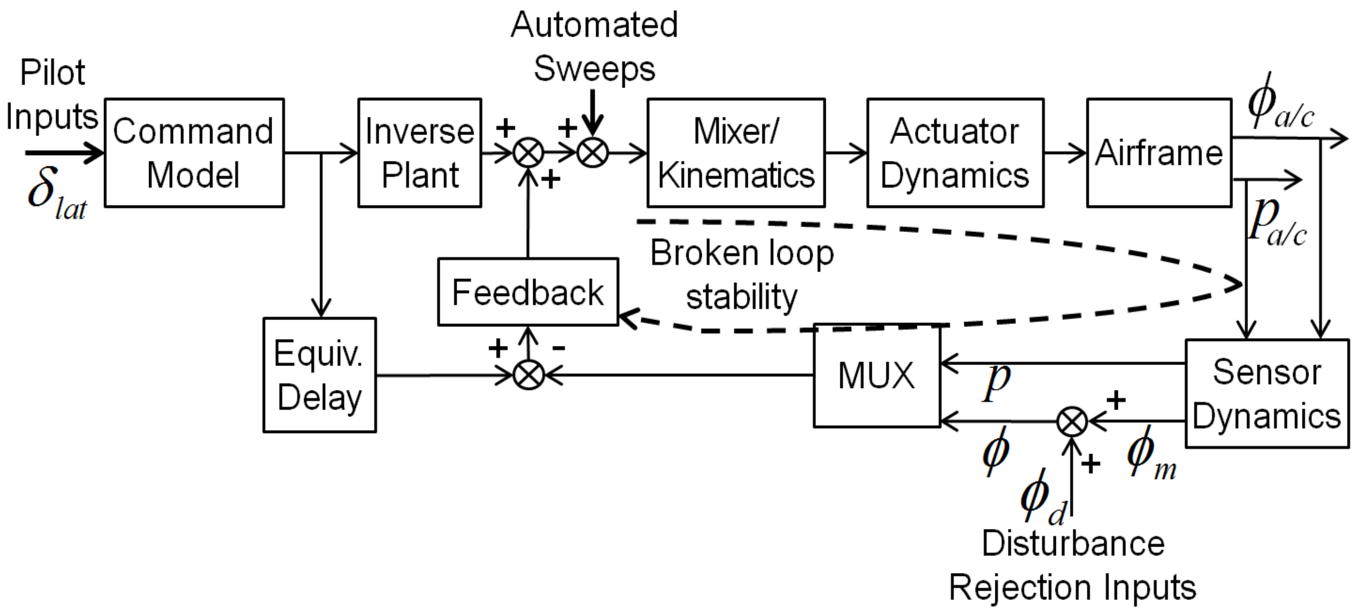

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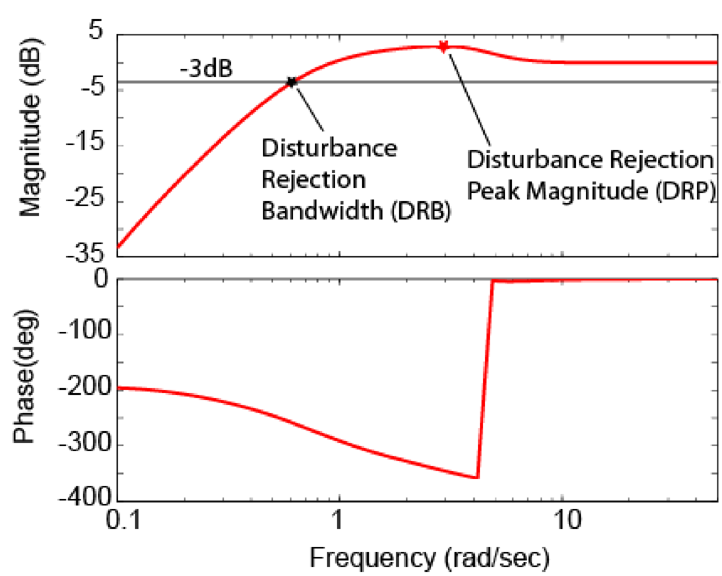

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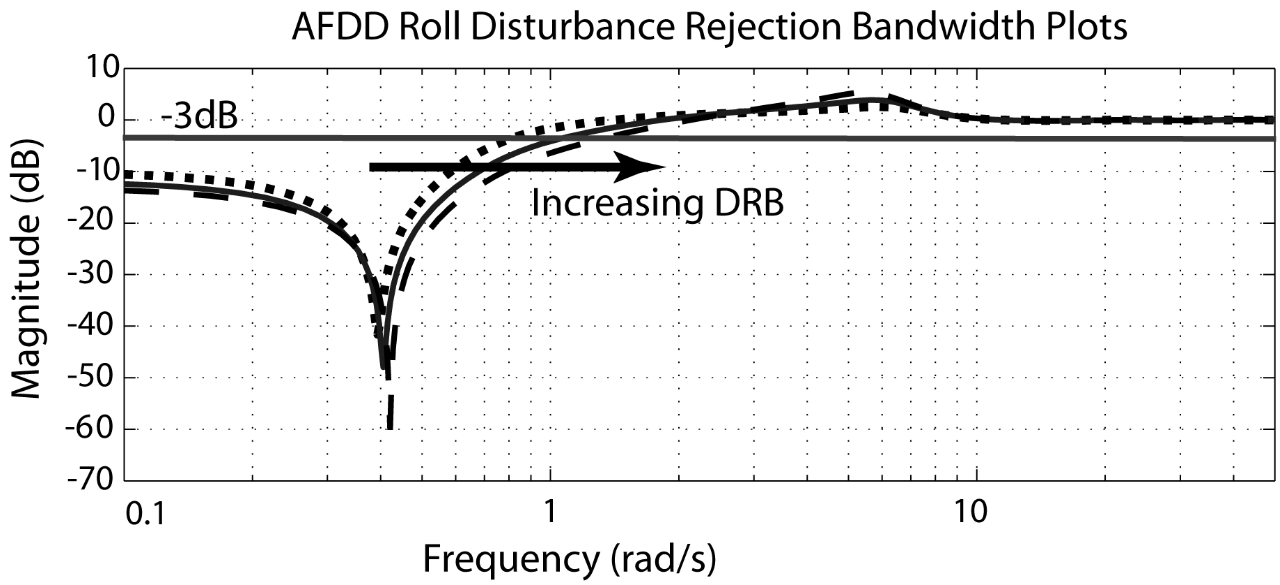

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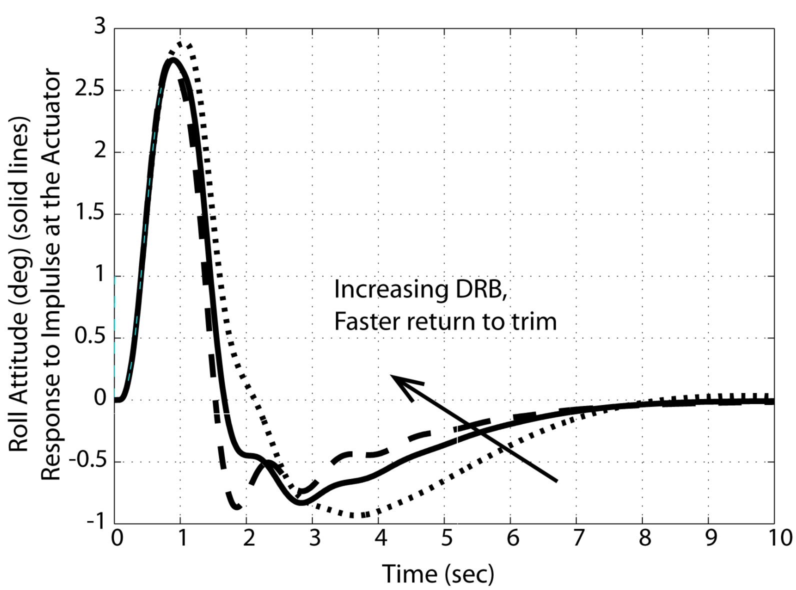

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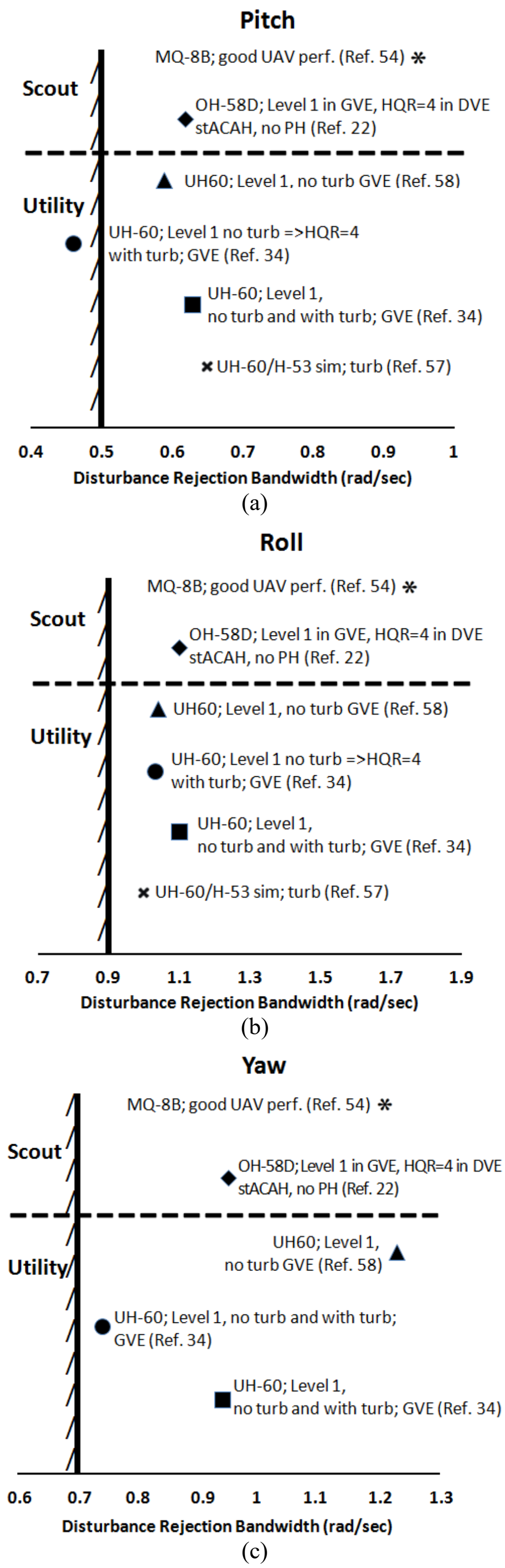

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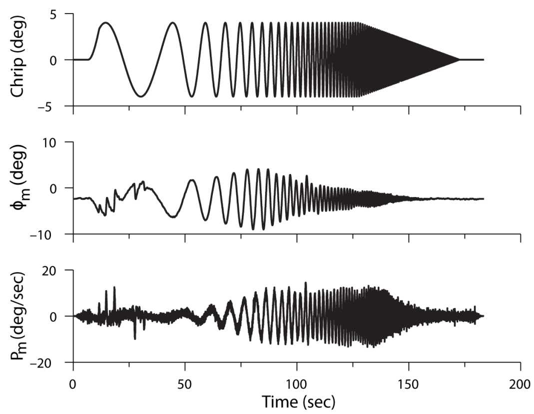

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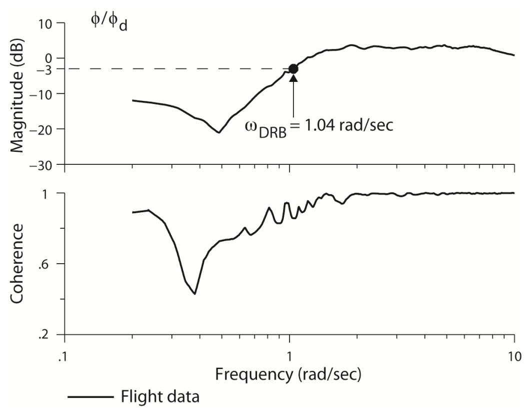

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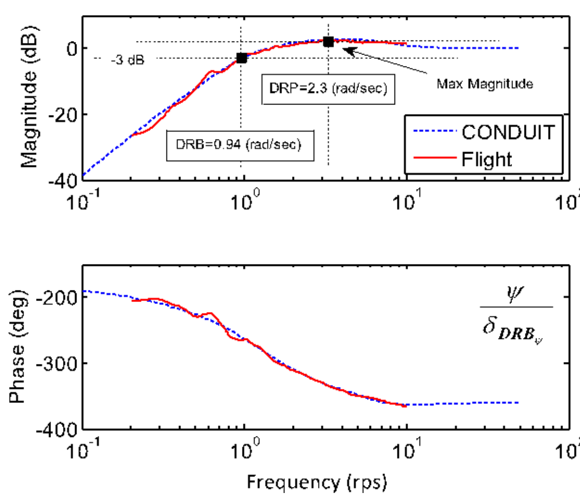

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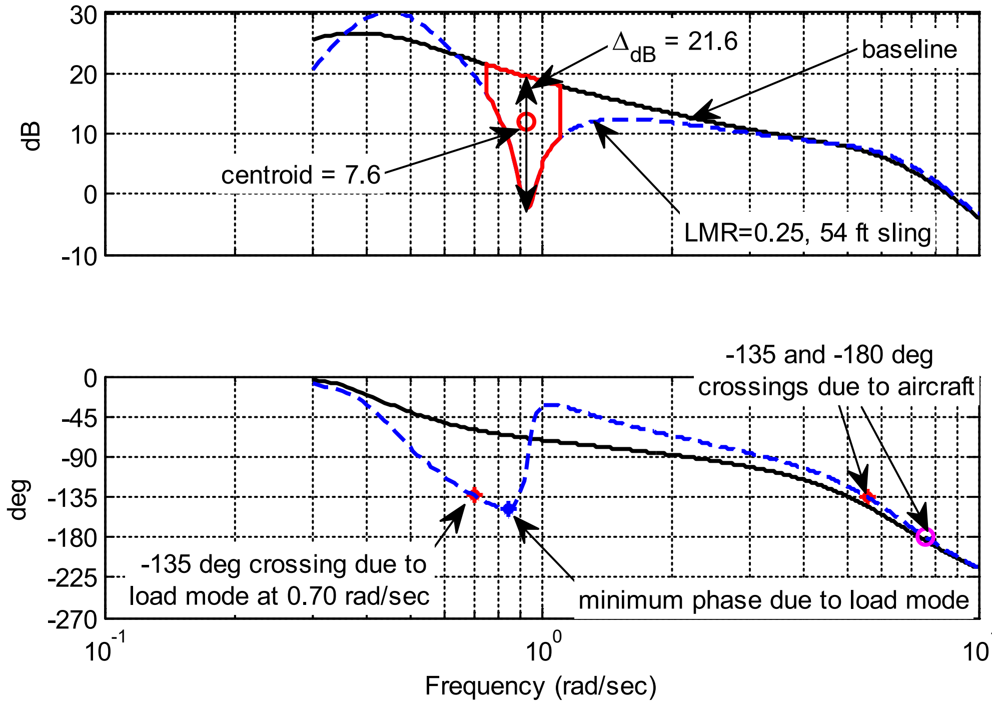

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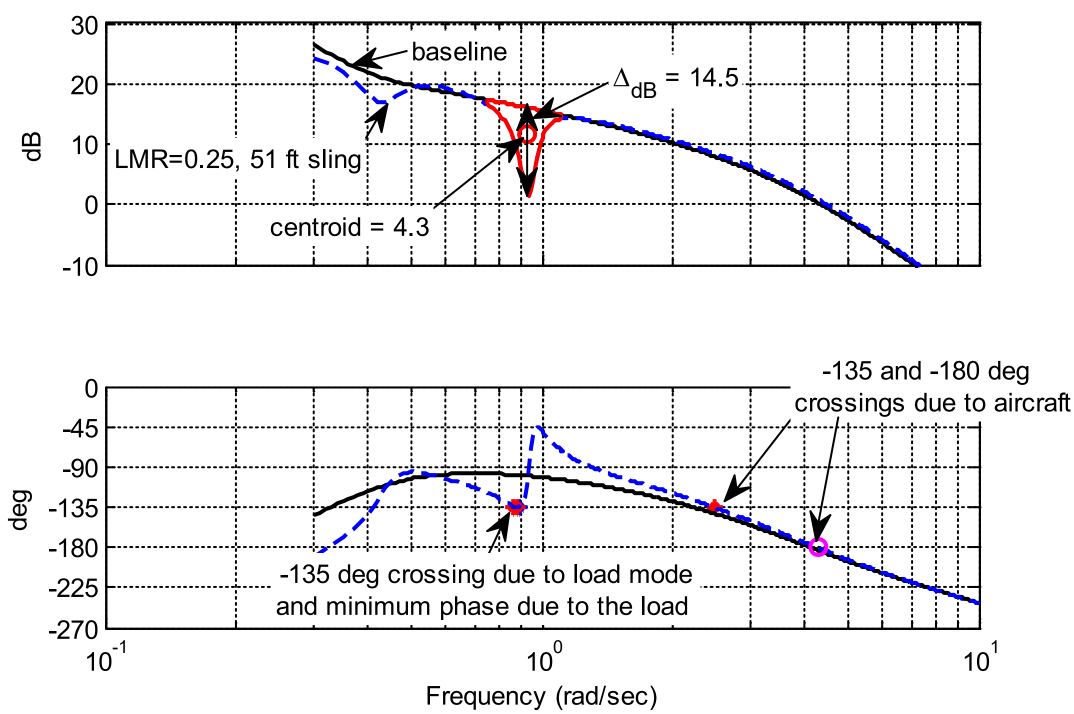

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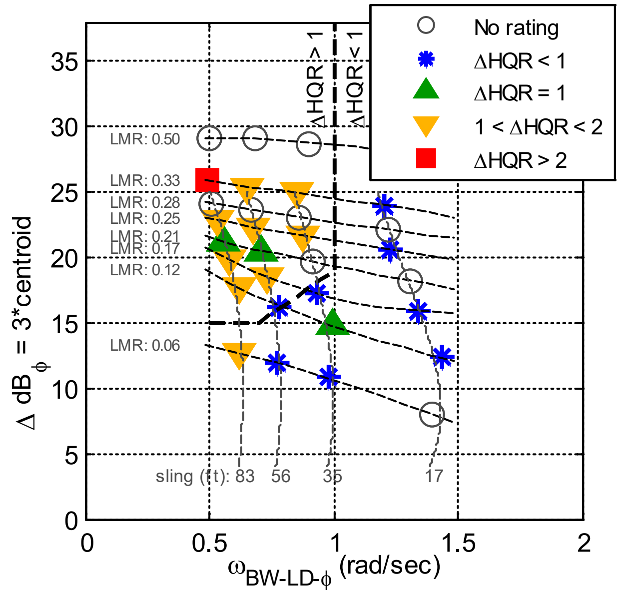

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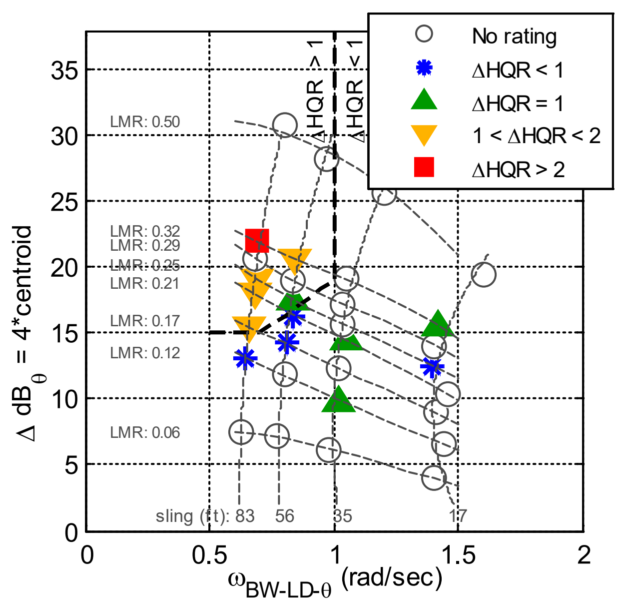

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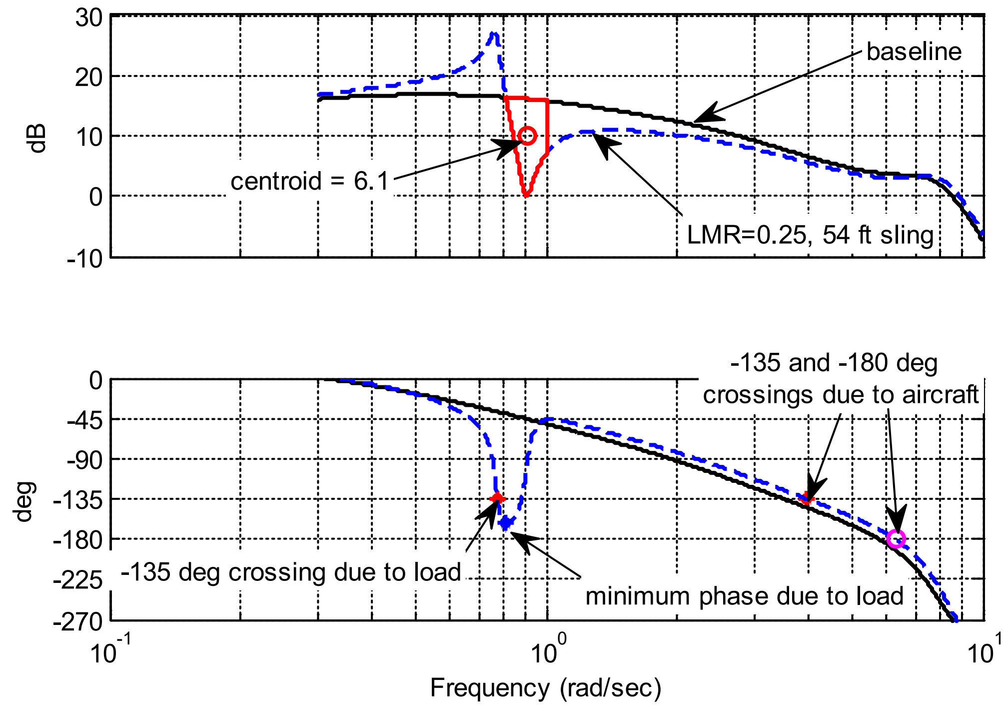

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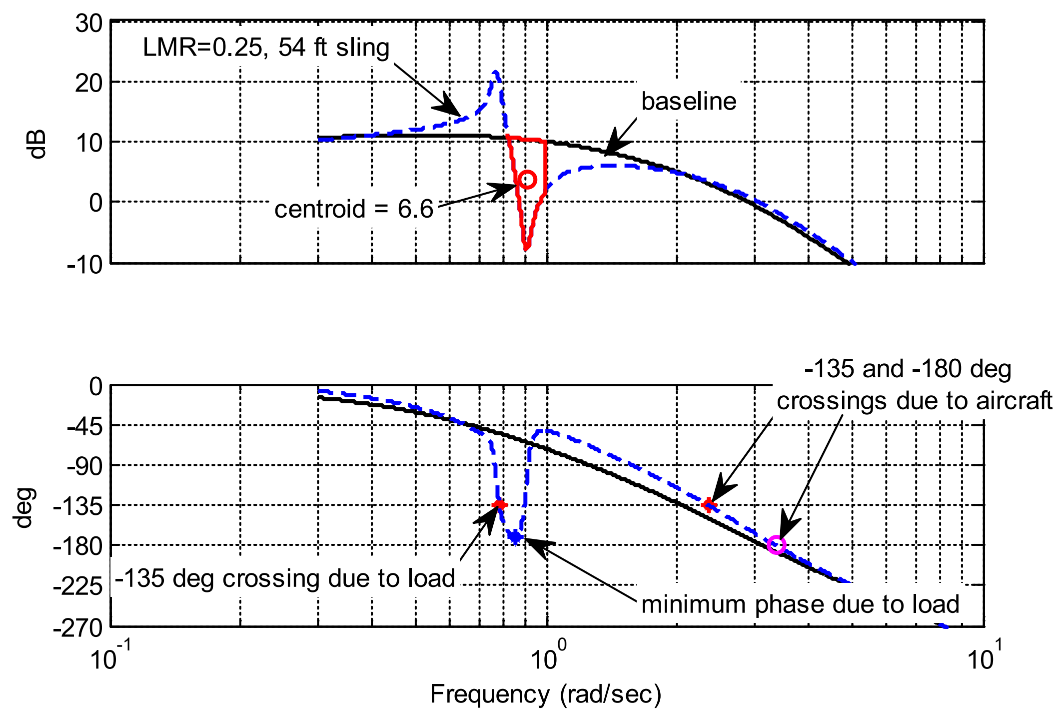

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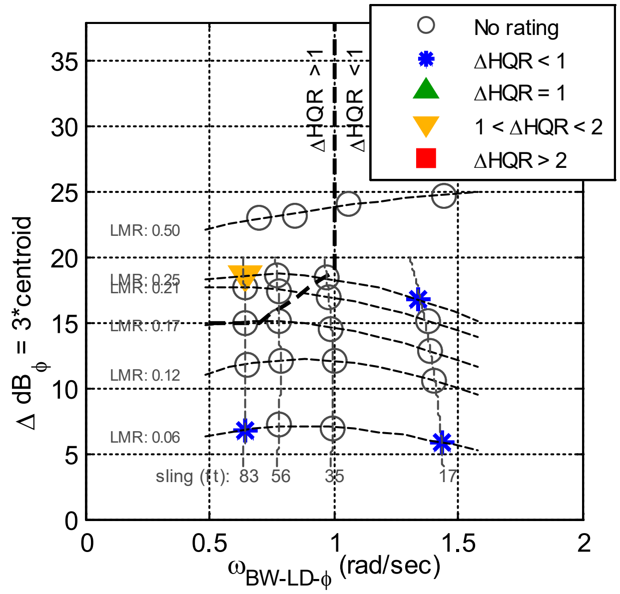

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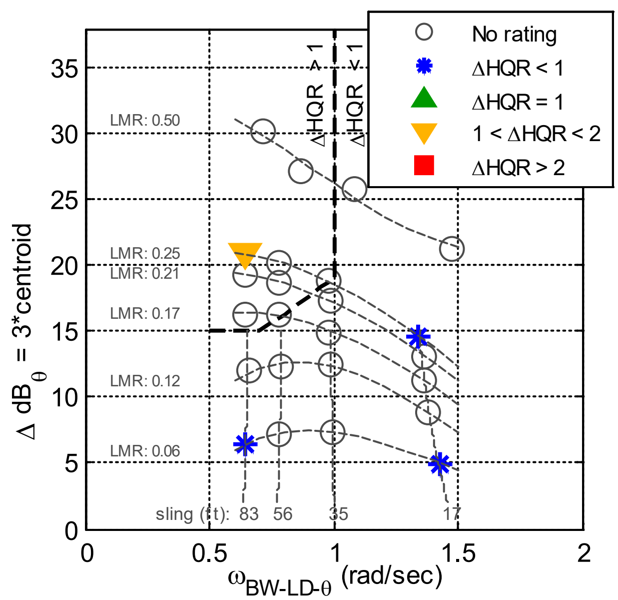

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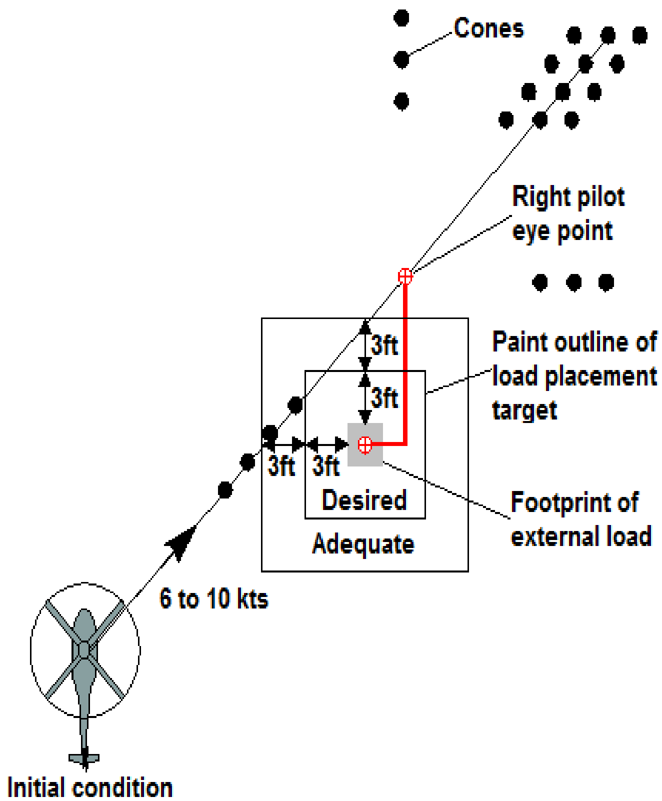

Figure 25. Load Placement Mission Task Element (MTE) course.

Table 1. Proposed boundaries for disturbance rejection criteria.

	Pitch (θ)	Roll (ϕ)	Yaw (ψ)
DRB (rad/s) ≥	0.5	0.9	0.7
DRP (dB) ≤	5.0	5.0	5.0
	Surge (u)	Sway (v)	Heave (w)
DRB (rad/sec) ≥	0.34	0.54	1.0
DRP (dB) ≤	5.0	5.0	5.0
	Axial (x)	Lateral (y)	Vertical (h)
DRB (rad/sec) ≥	0.17	0.17	0.17
DRP (dB) ≤	3.0	3.0	3.0

Table 2. Precision Load Placement Mission Task Element (MTE) standards.

	Externally Slung Load	
	GVE	DVE
Desired Performance		N/A
Attain a controlled hover within X seconds of initiation of deceleration:	10 sec	
Maintain altitude during translation and hover within +/- X ft:	4 ft	
Controlled set-down of external load within X seconds of hover:	50 sec	
Load set-down position should be within a box +/- X ft larger than the footprint of the external load on all sides:	3 ft	
The load should have no perceptible drift at touchdown	✓	
Adequate Performance		N/A
Attain a controlled hover within X seconds of initiation of deceleration:	15 sec	
Maintain altitude during translation and hover within +/- X ft:	6ft	
Controlled set-down of external load within X seconds of hover:	120 sec	
Load set-down position should be within a box +/- X ft larger than the footprint of the external load on all sides:	6 ft	

APPENDIX 1

Proposed ADS-33F-PRF

23 April 2019

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T A B L E S

F I G U R E S

1. SCOPE

1.1 Scope

This specification contains the requirements for the flying and ground handling qualities of rotorcraft. It is intended that the specification should cover land-based rotorcraft which have primary missions ranging from scout and attack to utility and cargo. Additional requirements or modified standards may be required for rotorcraft that have to operate from small ships in sea states resulting in more than small ship motion.

Intended use is described in 6.1.

1.2 Application

The requirements of this specification are intended to assure that no limitations on flight safety or on the capability to perform intended missions will result from deficiencies in flying qualities. Flying qualities for the rotorcraft shall be in accordance with the provisions of this specification unless specific deviations are authorized by the Government. Additional or alternate special requirements may be specified by the procuring activity. For example, if the form of a requirement should not fit a particular vehicle configuration or control mechanization, the Government may, at its discretion, agree to a modified requirement that will maintain an equivalent degree of acceptability.

2. APPLICABLE DOCUMENTS

2.1 Government documents

N/A

2.2 Specifications, standards, and handbooks

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the Department of Defense Index of specifications and Standards (DoDISS) and supplement thereto, cited in the solicitation.

SPECIFICATIONS

(Unless otherwise indicated, copies of the above specifications, standards, and handbooks are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094)

2.3 Other Government documents, drawings, and publications

N/A

2.4 Non-Government publications

N/A

2.5 Order of precedence

In the event of a conflict between the text of this specification and the references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 General

3.1.1 Operational missions and Mission-Task-Elements (MTEs)

The system specification will define the operational missions and will specify the Mission-Task-Elements to be considered by the contractor in designing the rotorcraft to meet the requirements of this specification. These Mission-Task-Elements will represent the entire spectrum of intended operational usage and will in most cases be selected from those listed in Table I. The system specification will, for each specified MTE, define the level of Degraded Visual Environment (DVE) required, that is, Usable Cue Environment 2 or 3.

3.1.2 Required agility

Many of the quantitative criteria have multiple boundaries that discriminate between rotorcraft that have to maneuver precisely and aggressively and those that can accomplish their mission tasks with limited agility and maneuverability. Table I indicates which limit shall be met by associating a required agility with the intended MTEs. If no criterion is provided for the required agility, the next available lower value shall apply.

3.1.3 Operational environment

The system specification will specify the operational environment that must be considered by the contractor in designing the rotorcraft to meet the flying qualities requirements of this standard. Parameters to be defined include the following:

a. Degraded Visual Environment (DVE).
b. The IMC capability required.
c. The angle and azimuth for slope take-offs and landings.
d. The degree of divided attention operation.
e. Applicability of rotor start and stop capabilities for shipboard operations (3.8.1.1).
f. Applicability of ditching requirements (3.8.4).

3.1.4 Multi-crew rotorcraft

Unless otherwise stated, all requirements shall apply for the primary pilot station. The system specification will define the Mission-Task-Elements, Degraded Visual Environment, degree of divided attention, and Level of Flying Qualities that are applicable to any other pilot stations.

3.1.5 Levels of handling qualities

The overall rotorcraft Level of handling qualities shall be a combination of the two distinct methods of assessment, Predicted Levels and Assigned Levels.

3.1.5.1 Predicted Levels of handling qualities

To obtain the Predicted Levels of handling qualities, the rotorcraft's flying qualities parameters shall be determined and compared with the criteria limits appropriate to the rotorcraft's operational requirements. For the predicted Level of handling qualities to be Level 1, the rotorcraft shall meet the Level 1 standards for all of the criteria. Violation of any one requirement is expected to degrade handling qualities. Violation of several individual requirements (e.g., to Level 2) could have a synergistic effect so that, overall, the handling qualities degrade to Level 3, or worse.

3.1.5.2 Assigned Levels of handling qualities

To determine the Assigned Level of handling qualities, test pilots shall use the Cooper-Harper Handling Qualities Rating (HQR) Scale (Figure 1) to assess the workload and task performance required to perform the designated MTEs. For the assigned Level of handling qualities to be Level 1, the rotorcraft shall be rated Level 1 as defined in Section 3.10 for all of the MTEs designated as appropriate to the rotorcraft's operational requirements. The Government shall judge the acceptability of any degradations when performing an MTE in light winds, and with load mass ratios greater than 0.33.

3.1.5.3 Interpretation of Predicted versus Assigned Levels of handling qualities

Failing only one or two of the predicted criteria by a small margin shall not necessarily determine the overall outcome. To resolve this, assessment of appropriate MTEs shall be the deciding factor. The MTEs to be used for such testing must be mutually agreed upon by the contractor and Government. The MTE assessment shall be conducted in flight or on a validated simulator, obtaining the HQRs per the methodology defined in Section 3.10 of the specification.

3.1.6 Flight envelopes

The Flight Envelopes shall be defined and shall clearly indicate the effects of rotorcraft configuration, loadings, settings and states.

3.1.6.1 Operational Flight Envelopes (OFE)

The Operational Flight Envelopes shall define the boundaries within which the rotorcraft must be capable of operating in order to accomplish the operational missions of 3.1.1. These envelopes shall be defined in terms of combinations of airspeed, altitude, load factor, rate-of-climb, side-velocity, and any other parameters specified by the system specification, as necessary to accomplish the operational missions. Any warnings or indications of limiting or dangerous flight conditions, required by 3.1.15, shall occur outside the OFEs.

3.1.6.2 Service Flight Envelopes (SFE)

The Service Flight Envelopes shall be derived from rotorcraft limits as distinguished from mission requirements. These envelopes shall be expressed in terms of the parameters used to define the OFEs, plus any additional parameters deemed necessary to define the appropriate limits. The inner boundaries of the SFEs are defined as coincident with the outer boundaries of the OFEs. The outer boundaries of the SFEs are defined by one or more of the following: uncommanded rotorcraft motions, or structural, engine/power-train, or rotor system limits. The magnitude of the differences between the inner and outer boundaries of the SFEs shall be based on the guarantee of adequate margins as required by 3.1.15.

3.1.7 Configurations

The configurations required for performance of the operational missions of 3.1.1 shall be defined.

3.1.8 Loadings

The possible Loadings for the Configurations defined in 3.1.7 shall be determined.

3.1.9 Flight conditions

The flight conditions where significant handling qualities effects or changes occur shall be defined.

3.1.10 Settings

The Settings that are available to the pilot shall be defined.

3.1.11 States

The Settings and Failure States that correspond to failure probabilities allowed by Table II shall be determined.

3.1.12 Rotorcraft status

For each of the Settings and States defined in 3.1.10 and 3.1.11 a set of Loadings, Configurations, and Flight Conditions shall be selected by the contractor for demonstrating compliance with this specification. This selection shall include combinations that are critical from the point of handling qualities, and shall be submitted to the Government for approval.

3.1.13 Levels for Normal States

The minimum Levels of flying qualities shall be Level 1 in the Operational Flight Envelopes and Level 2 in the Service Flight Envelopes.

3.1.13.1 Flight beyond the Service Flight Envelopes

Flight beyond the Service Flight Envelope that does not involve structural failure, or unrecoverable loss of rotor RPM, shall be recoverable to the SFE without undue pilot skill.

3.1.14 Rotorcraft failures

The allowable degradation in handling qualities due to one or more system failures is specified in Table II as a function of the probability per flight hour that the failed state will be encountered. The degradation in handling qualities is quantified in terms of Levels, by application of the criteria in Sections 3.2 through 3.9, and piloted evaluations of MTEs in Section 3.10.

The methodology for calculating the handling qualities Level for each failed state is given below:

a. Review the Failures Modes and Effects Analysis (FMEA) and identify and tabulate all failures that are expected to adversely affect handling qualities.

b. Calculate the ADS-33 criterion parameters (e.g., Bandwidth and Phase Delay, Attitude Quickness, etc.) for each of the tabulated failures.

c. Plot the parameters on the criterion boundaries (e.g., Bandwidth vs. Phase Delay), and note the Level that results. The criterion that results in the highest Level (most degraded handling qualities) defines the Level associated with that failure. Accomplish for all failures identified as adversely affecting handling qualities.

d. Enter Table II with the probability of encountering each Level to determine compliance. The probability of encountering a given Level is obtained from the System Safety Analysis (sum of probabilities of all independent failures that result in that Level).

For cases where failing one or two criteria by a small margin for a given failure are in conflict with company flight or simulation results, it is acceptable to conduct MTEs that would expose the identified deficiency. The HQRs resulting from that testing may be used as demonstration of compliance. The MTEs to be used for such testing must be mutually agreed upon by the contractor and the Government.

3.1.14.1 Transients following failures

The transient following a failure or combination of flight control system failures shall be recoverable to a safe steady flight condition without exceptional piloting skill. The attitude excursion following a failure shall not exceed the following limits with the pilot's hands and feet off the controls for a specified time delay.

<u>Forward Flight VFR and Dual Pilot IFR</u>

- 30 degrees pitch change from trim
- 60 degrees roll change from trim

<u>Forward Flight Single Pilot IFR</u>

- 20 degrees pitch change from trim followed immediately by clear pitch motion to return trim with no pilot intervention.
- 30 degrees roll change from trim followed immediately by clear roll motion to return trim with no pilot intervention.

<u>Low Speed and Hover</u>

- 10 degrees pitch change from trim
- 15 degrees roll change from trim

For Low Speed the time delay from occurrence of the failure to pilot takeover is 1.5 seconds.

For Hover, Takeoff, and Landing, the time delay from occurrence of the failure to pilot takeover is 0.5 seconds.

<u>For forward Flight, the following time delays apply.</u>

- Maneuvering with hands on the controls – 1.5 seconds

- Instrument approach – 1.5 seconds
- Climb, cruise, and descent with hands off the controls – 3.5 seconds.
- Flight above V_H – 1.5 seconds.

The anti-torque pedal required to eliminate a yaw transient shall not exceed 50% of pedal authority.

3.1.14.2 Indication of failures

Immediate and easily interpreted indications of failures shall be provided, if such failures require a change of strategy or crew action.

3.1.15 Rotorcraft limits

Limiting and potentially dangerous conditions may exist where the rotorcraft should not be flown. The pilot shall be provided with clear and unambiguous warnings and indications of approaches to rotorcraft limits. A 10% control margin shall exist throughout the OFE. In near-earth operations, the warnings and indications shall be interpretable by the pilot with eyes out of the cockpit.

3.1.15.1 Devices for indication, warning, prevention, and recovery

It is preferred that limiting and dangerous flight conditions be eliminated and the requirements of this specification be met by appropriate aerodynamic and structural design rather than through incorporation of special devices for indication, warning, prevention, and recovery. However, if such devices are used, normal or inadvertent operation shall not create a hazard to the rotorcraft, or prohibit flight within the Operational Flight Envelope.

3.1.16 Residual oscillations

Any sustained oscillations in any axis in calm air shall not interfere with the pilot's ability to perform the specified Mission-Task-Elements. For Level 1, oscillations in attitude and in acceleration at the pilot's station greater than 0.5 degrees and 0.05g shall be considered excessive for any Response-Type and Mission-Task-Element. These requirements shall apply with the cockpit controls fixed and free. Residual motions that are classified as a vibration shall be excluded from this requirement. Residual motions that are to be classified as vibrations shall be subject to Government approval.

3.2 Response-Types

The required Response-Types depend on the applicable MTE and the Usable Cue Environment. The specified Response-Types are intended to be minimums, although another Response-Type may be provided if superior or equivalent flying qualities can be demonstrated.

3.2.1 Determination of the Usable Cue Environment

The Usable Cue Environment (UCE) shall be obtained from Figure 3 using visual cue ratings (VCRs) obtained from the flight assessments specified below. The VCRs shall be made by at least three pilots using the scale shown in Figure 2. The mean VCRs for each task shall be obtained by separately taking the average of all the pilot ratings in each axis. This will result in five average VCRs for each task: pitch, roll, and yaw attitude, and vertical and horizontal translational rate. This shall be reduced to two VCRs by taking the worst (numerically highest) average VCR among pitch, roll and yaw attitude, and between vertical and horizontal translational rate, for each task. These VCRs for attitude and translational rate shall be plotted on Figure 3 to obtain a UCE for each task. Points falling on a boundary in Figure 3 shall be considered to lie in the region of numerically higher UCE. The largest UCE value obtained in this process shall be used in Table III to determine the required Response-Type. The visual cue ratings shall be determined using all displays and vision aids that are expected to be operationally available to the pilot, in the Degraded Visual Environments specified in 3.1.3.

3.2.1.1 Characteristics of test rotorcraft

The test rotorcraft shall have response characteristics that rank no higher than a Rate Response-Type as defined in 3.2.6. It shall be shown to be a Level 1 rotorcraft by demonstrating compliance with the applicable MTEs specified in 3.2.1.2, performed to DVE standards but in the GVE (UCE = 1).

3.2.1.2 Applicable Mission-Task-Elements

The following Mission-Task-Elements shall be flown when making the UCE assessments: Hover, Landing, Pirouette, Acceleration and Deceleration (or Depart/Abort), Sidestep (or Lateral Reposition), and Vertical Maneuver. The task descriptions and DVE performance limits specified in 3.10 for each of these maneuvers shall apply when making the VCR determinations.

3.2.1.3 Dispersions among visual cue ratings

Subject to Government approval, a level of UCE shall be assigned or additional pilots shall be used if the standard deviation of the individual visual cue ratings among the pilots is greater than 0.75.

3.2.2 Required Response-Types

The Response-Types shall be in accordance with Table III for hover and low speed, and Table IV for forward flight. These required Response-Types are intended to be minimums, although another Response-Type may be provided if superior or equivalent handling qualities can be demonstrated. If such another Response-Type is selected, the requirements in 3.3 and 3.4 shall apply, and if the contractor asserts that a requirement of 3.3 and/or 3.4 does not apply, one or more MTEs shall be selected and mutually agreed upon by the contractor and Government to ensure superior or equivalent flying qualities are achieved.

3.2.2.1 Relaxation for Altitude (Height) Hold

A requirement for Vertical Rate Command with Altitude (Height) Hold may be relaxed if the Vertical Translational Rate Visual Cue Rating is 2 or better and divided-attention operation is not required. The vertical response shall meet the definition of a Vertical Rate Response-Type (3.2.10).

3.2.2.2 Additional Level 1 requirement for Turn Coordination

Turn Coordination (TC) (3.2.11.1) shall be provided as an available Response-Type for the slalom MTE in low-speed flight and for Single Pilot IFR in forward flight. TC is not required at airspeeds below 15 knots.

3.2.2.3 Alternative for ACAH in Forward Flight

For Single Pilot IFR operations in Forward Flight, the ACAH response-type may be replaced with an autopilot that meets the requirements of Section 3.2.2.4.

3.2.2.4 Requirement for Autopilot

The autopilot shall have heading select/hold and altitude hold functions.

3.2.3 Response-Type ranking

The rank-ordering of combinations of Response-Types from least to most stabilization shall be defined as:

1. RATE
2. RATE+RCDH
3. ACAH+RCDH
4. ACAH+RCDH+RCHH
5. ACAH+RCDH+RCHH+PH
6. TRC+RCDH+RCHH+PH

A specified Response-Type may be replaced with another Response-Type if superior or equivalent handling qualities can be demonstrated. For UCE=1 it is important to insure that the higher rank of stabilization does not preclude meeting the moderate and large amplitude requirements.

TRC is not recommended for pitch pointing.

3.2.4 Combinations of degraded Response-Type and dynamics in degraded UCE

In UCE > 1, a combination of Level 2 Response-Type (Table III or Table IV) and Level 2 dynamic characteristics (3.3 or 3.4) shall be interpreted as Level 3.

3.2.5 Rotorcraft guidance

For near-earth operations at night and in poor weather (UCE > 1), sufficient visual cues shall be provided to allow the pilot to navigate over the terrain, and to maneuver the rotorcraft to avoid obstacles while accomplishing the Mission-Task-Elements.

3.2.6 Character of Rate and Rate Command Response-Types

A response that exhibits a monotonic or oscillatory divergence in attitude or airspeed following a pulse control input of the cockpit controller is defined as a Rate Response-Type. For pulse input to the longitudinal or lateral controller, feet may remain on the pedals. For a pulse input to the pedals, hands may remain on the pitch/roll controller. For a Rate Command response, a step input of the cockpit controller force shall produce a linear time response in pitch, roll, or yaw attitude

3.2.7 Character of Attitude Hold and Heading Hold Response-Types

If Attitude Hold or Heading (Direction) Hold is specified as a required Response-Type in 3.2.2 the response to a pulse input shall be as illustrated in Figure 4. The pulse shall be inserted directly into the control actuator, unless it can be demonstrated that a pulse cockpit controller input will produce the same response. The maximum required attitude/heading displacement from trim is ±10 degrees for pitch and heading, and ±20 degrees for roll.

Attitude and heading shall return to within one degree for all attitude/heading changes up to 10 degrees, and to within 10 percent of peak for attitude/heading changes above 10 degrees, following a pulse input, in less than 10 seconds for UCE=1, and in less than 7 seconds for UCE>1 or flight in IMC.

The attitude or heading shall remain within the specified limit for at least 30 seconds for Level 1.

For forward flight, this requirement is considered satisfied in the longitudinal axis if after disturbing the airspeed by at least 10 kts from trim, releasing the cyclic results in a return to within 10% of the trim airspeed at an average rate of at least 2 kt/sec, and achieves steady state with a damping ratio of at least 0.35.

3.2.7.1 Additional requirement for Heading Hold in Hover

For Heading Hold, following a release of the directional controller the rotorcraft shall capture the reference heading (in degrees) with transient excursions limited to one overshoot, which shall not exceed 2.5 degrees. In no case shall a divergence result from activation of the Heading Hold mode.

3.2.8 Character of Attitude Command Response-Types

If Attitude Command is specified as a required Response-Type in 3.2.2, a step cockpit pitch (roll) controller force input shall produce a time response with respect to the trimmed pitch (roll) attitude that reaches steady state, or peaks in 6 seconds or less, and asymptotically approaches a constant value, that is equal to or less than the peak value and has the same sign as the peak value. A separate trim control shall be supplied to allow the pilot to null the cockpit controller forces at any achievable steady attitude. Trim changes shall occur within 0.25 seconds of pressing force trim release button. If no separate trim control provided, request for deviation to include Level 1 for four MTEs.

For Hover and Low-Speed, regardless of attitude response, this requirement is satisfied if the resulting inertial translational longitudinal (lateral) acceleration is constant, or its absolute value is asymptotically decreasing towards a constant.

For Forward Flight, this requirement shall apply for cyclic force inputs equal to at least three pounds or a deflection of one inch, whichever is less. This requirement may also be satisfied in the longitudinal axis if:

a. The gradient of longitudinal cyclic position vs. airspeed is less than or equal to 0.04 kt/in about the trim airspeed, and

b. The attitude hold requirement of 3.2.7 is met.

3.2.9 Character of Translational Rate Response-Types

If Translational Rate Command is specified as a required Response-Type in 3.2.2, constant pitch and roll controller force and deflection inputs shall produce a proportional steady translational rate, with respect to the earth, in the appropriate direction.

3.2.10 Character of Vertical Rate Response-Types

The rotorcraft shall be defined as having a Vertical Rate Response-Type if a constant deflection (force if an isometric controller is used) of the vertical axis controller from trim produces a constant steady-state vertical velocity. Provision shall be provided for the pilot to null the cockpit controller force at any achievable vertical rate.

3.2.10.1 Character of Vertical Rate Command with Altitude (Height) Hold

If Vertical RCHH (Rate Command with Altitude (Height) Hold) is specified as a required Response-Type in 3.2.2, following an altitude deviation induced by insertion and removal of an input directly into the vertical-axis actuator, the rotorcraft shall return to its original altitude without objectionable delays and with no overshoot. For hover and low speed, the rotorcraft shall automatically hold altitude with respect to a flat surface for land-based operations, or with respect to the mean surface/flight deck deviation for a rough sea or sea-based operations, with the altitude controller free. For Level 1, the altitude deviation during the performance of the following MTEs shall not exceed desired DVE performance requirements of the Hover, Hovering Turn, Pirouette, and either Sidestep for Scout-Attack categories, or Lateral Reposition for Utility and Cargo categories. Engagement of Altitude Hold shall be obvious to the pilot through clear tactile and visual indication. The pilot shall be provided with a means to disengage Altitude Hold, change altitude, and reengage Altitude Hold without removing his hands from the flight controls.

3.2.11 Character of yaw response to lateral controller

3.2.11.1 Turn coordination

For low-speed and forward flight, during banked turns with any available Heading Hold modes disengaged, the rotorcraft heading response to lateral controller inputs shall remain sufficiently aligned with the direction of flight so as not to be objectionable to the pilot. Complex coordination of the yaw and roll controls shall not be required.

3.2.11.2 Rate Command with Heading (Direction) Hold

For hover, the yaw controller inputs required to maintain constant heading during rolling maneuvers shall not be objectionably large or complex.

3.2.12 Limits on nonspecified Response-Types

It may be desirable, or even necessary, to incorporate Response-Types that are not explicitly defined in this specification. Examples of such Response-Types are Airspeed Hold, Linear Acceleration Command with Velocity Hold, and hybrid responses such as ACAH for small attitudes that blend to Rate for larger commands or attitudes. These Response-Types shall meet the requirements of this specification. In addition, their operation shall not result in excessive excursions in rotorcraft attitudes, or require objectionably complex or unfamiliar control strategies.

3.2.13 Requirements for inputs to control actuator

Control input shaping may be used to achieve the necessary command-response relationship for backup flight control systems. The requirements to check for adequate disturbance rejection via inputs directly into the control actuator (3.2.7 and 3.2.10.1) shall be waived for Levels 2 and 3.

3.2.14 Transition between airborne and ground operations

There shall be no tendency for uncommanded, divergent motions of any primary flight control surface when the rotorcraft is in contact with any potential landing platform. This requirement is aimed specifically at integrators in the flight control system that must be turned off when rotorcraft motion is constrained by contact with a fixed object.

3.3 Hover and low speed requirements

The hover and low speed requirements shall apply throughout the applicable portions of the Operational and Service Flight Envelopes for operations up to 45 knots ground speed.

3.3.1 Equilibrium characteristics

The equilibrium pitch and roll attitudes required to achieve a no-wind hover, and to achieve equilibrium flight in a 35 knot relative wind from any direction, shall not result in pilot discomfort, disorientation, or restrictions to the field-of-view that would interfere with the accomplishment of the Mission-Task-Elements of 3.1.1. Nose-up trim attitudes that potentially result in tail boom clearance problems are discouraged.

3.3.2 Small-amplitude pitch (roll) attitude changes

3.3.2.1 Short-term response to control inputs (bandwidth)

The pitch (roll) response to longitudinal (lateral) cockpit control position inputs shall meet the limits specified in Figure 5. The bandwidth (ω_{BW}) and phase delay (τ_p) parameters shall be obtained from frequency responses as defined in Figure 6. It is desirable to also meet this criterion for controller force inputs. If the bandwidth for force inputs falls outside the specified limits, flight testing shall be conducted to determine that the force feel system is not excessively sluggish. For Attitude Command Response-Types, if the bandwidth defined by gain margin is less than the bandwidth defined by phase margin, or is undefined, the rotorcraft may be PIO prone. In this case flight testing shall be performed to determine acceptability.

3.3.2.2 Short-term pitch and roll responses to disturbance inputs

If Attitude Hold is specified as a required Response-Type in 3.2.2 and the system meets the Character of Attitude Hold Response-Type requirement in 3.2.7, the attitude response to disturbance input as defined in Figure 7 shall meet the limits specified in Table V, where the Disturbance Rejection Bandwidth (DRB) is calculated as frequency at which the sensitivity function of the hold variable crosses -3 dB and Disturbance Rejection Peak (DRP) is defined as the peak magnitude of the sensitivity function of the hold variable. The DRB and DRP parameters shall be obtained from frequency responses as defined in Figure 8.

3.3.2.3 Mid-term response to control inputs

The mid-term response characteristics shall apply at all frequencies and for oscillations of all magnitudes that are noticeable to the pilot. Use of an Attitude Hold Response-Type shall constitute compliance with this requirement, as long as any oscillatory modes following a cockpit controller pulse input have an effective damping ratio of at least $\zeta = 0.35$. If Attitude Hold is not available, the applicable criterion shall depend on the degree of pilot attention according to 3.1.3. The lack of oscillations implies compliance.

3.3.2.3.1 <u>Fully attended operations</u>

The mid-term response shall meet the limits of Figure 9.

3.3.2.3.2 <u>Divided attention operations</u>

The limits of Figure 9 shall be met, except that the Level 1 damping ratio shall not be less than $\zeta = 0.35$ at any frequency.

3.3.3 Moderate-amplitude pitch (roll) attitude changes (attitude quickness)

The ratio of peak pitch (roll) rate to change in pitch (roll) attitude, $q_{pk}/\Delta\theta_{pk}$ $(p_{pk}/\Delta\phi_{pk})$, shall meet the limits specified in Figure 10. The required attitude changes shall be made as rapidly as possible from one steady attitude to another without significant reversals in the sign of the cockpit control input relative to the trim position. The attitude changes required for compliance with this requirement shall vary from 5 deg in pitch (10 deg in roll) to the limits of the Operational Flight Envelope or 30 deg in pitch (60 deg in roll), whichever is less. It is not necessary to meet this requirement for Response-Types that are designated as applicable only to UCE = 2 or 3.

3.3.4 Large-amplitude pitch (roll) attitude changes

The achievable angular rate (for Rate Response-Types) or attitude change from trim (for Attitude Response-Types) shall be at least those specified in Table VI. The specified rates or attitudes shall be achieved in each axis while limiting excursions in the other axes with the appropriate control inputs. Response-Types that are designated as applicable exclusively to UCE = 2 or 3 are only required to meet the Limited agility requirements (3.1.2).

3.3.5 Small-amplitude yaw attitude changes

3.3.5.1 Short-term response to yaw control inputs (bandwidth)

The yaw response to directional cockpit control position inputs shall meet the limits specified in Figure 11. The bandwidth ($\omega_{BW\psi}$) and phase delay (τ_{p_ψ}) parameters are obtained from frequency responses as defined in Figure 6. It is desirable to also meet this criterion for controller force inputs. If the bandwidth for force inputs falls outside the specified limits, flight testing shall be conducted to determine that the force feel system is not excessively sluggish.

3.3.5.2 Short-term yaw response to disturbance inputs

If Heading (Direction) Hold is specified as a required Response-Type in 3.2.2 and the system meets the Character of Heading Hold Response-Type requirement in 3.2.7, the heading response to disturbance input as defined in Figure 7 shall meet the limits specified in Table V where the Disturbance Rejection Bandwidth (DRB) and Peak (DRP) parameters shall be obtained from frequency responses as defined in Figure 8.

3.3.5.2.1 Yaw rate response to lateral gusts

The peak yaw rate within the first three seconds following a step lateral gust input shall be such that the ratio, r_{pk}/V_g, shall not exceed 0.30 (deg/sec)/(ft/sec) for Level 1 or 1.0 (deg/sec)/(ft/sec) for Level 2. This requirement shall apply for lateral gust magnitudes from 10 to 25 knots in the presence of a steady wind of up to 25 knots from the most critical direction, except that the total wind velocity need not exceed 35 knots. Flight testing for this requirement shall not be required.

3.3.5.3 Mid-term response to control inputs

The mid-term response characteristics shall apply at all frequencies and for oscillations of all magnitudes that are noticeable to the pilot. Use of a Heading Hold Response-Type shall constitute compliance with this paragraph, as long as any oscillatory modes following a cockpit controller pulse input have an effective damping ratio of at least $\zeta = 0.35$. If Heading Hold is not available, the applicable criterion shall depend on the degree of pilot attention according to 3.1.3. The lack of oscillations implies compliance.

3.3.5.3.1 Fully attended operations

The mid-term response shall meet the requirements of Figure 9, except that the Level 1 limit on effective damping ratio for oscillations with natural frequencies greater than 0.5 rad/sec is relaxed from 0.35 to 0.19.

3.3.5.3.2 Divided attention operations

The limits of Figure 9 shall be met, except that the Level 1 damping ratio shall not be less than $\zeta = 0.19$ at any frequency.

3.3.6 Moderate-amplitude heading changes (attitude quickness)

The ratio of peak yaw rate to change in heading, $r_{pk}/\Delta\psi_{pk}$, shall meet the limits specified in Figure 12. The required heading changes shall be made as rapidly as possible from one steady heading to another and without significant reversals in the sign of the cockpit control input relative to the trim position. It is not necessary to meet this requirement for Response-Types that are designated as applicable only to UCE = 2 or 3.

3.3.7 Large-amplitude heading changes

The achievable yaw rate in hover shall be at least the values specified in Table VI. The specified angular rates shall be achieved about the yaw axis while limiting excursions in the other axes with the appropriate control inputs, and with main rotor RPM at the lower sustained operating limit. Response-Types that are designated as applicable only to UCE = 2 or 3 shall meet at least the Limited agility requirements (3.1.2).

3.3.8 Interaxis coupling

Control inputs to achieve a response in one axis shall not result in objectionable responses in one or more of the other axes.

3.3.8.1 Yaw due to collective for Aggressive agility

The yaw rate response to abrupt step collective control inputs with the directional controller fixed shall not exceed the boundaries specified in Figure 13. The directional controller may be free if the rotorcraft is equipped with a heading hold function. Pitch and roll attitudes shall be maintained essentially constant. In addition, there shall be no objectionable yaw oscillations following step or ramp collective changes in the positive and negative directions. Oscillations involving yaw rates greater than 5 deg/sec shall be deemed objectionable.

3.3.8.2 Pitch due to roll and roll due to pitch coupling for Aggressive agility

The ratio of peak off-axis attitude response from trim within 4 seconds to the desired (on-axis) attitude response from trim at 4 seconds, $\Delta\theta_{pk}/\Delta\phi_4$ $(\Delta\phi_{pk}/\Delta\theta_4)$, following an abrupt lateral (longitudinal) cockpit control step input, shall not exceed ±0.25 for Level 1 or ±0.60 for Level 2. Heading shall be maintained essentially constant.

3.3.8.3 Pitch due to roll and roll due to pitch coupling for Target Acquisition and Tracking

The pitch due to roll (q/p) and roll due to pitch (p/q) coupling for Target Acquisition and Tracking shall not exceed the limits specified in Figure 14. The average q/p and average p/q are derived from ratios of pitch and roll frequency responses. Specifically, average q/p is defined as the magnitude of pitch-due-to-roll control input (q/δ_{lat}) divided by roll-due-to-roll control input (p/δ_{lat}) averaged between the bandwidth and neutral-stability (phase = -180 deg) frequencies of the pitch-due-to-pitch control inputs (θ/δ_{lon}). Similarly, average p/q is defined as the magnitude (p/δ_{lon}) divided by (q/δ_{lon}) between the roll-axis (ϕ/δ_{lat}) bandwidth and neutral stability frequencies. Off-axis inputs shall be minimized while generating the frequency response data. Multi-input/multi-output frequency response identification techniques shall be used to analyze the frequency responses to account for the effect of inadvertent multiple-axis control inputs which may have been present during the excitation.

3.3.9 Response to collective controller

3.3.9.1 Height response characteristics

The vertical rate response shall have a qualitative first-order appearance for at least 5 seconds following a step collective input. If the most rapid input achievable is not a clear step, the time zero shall be defined as shown in Figure 15. Pitch, roll, and heading excursions shall be minimized. The limits on the parameters defined by the following equivalent first-order vertical-rate-to-collective transfer function shall be in accordance with Table VII.

$$\frac{\dot{h}}{\delta_c} = \frac{K e^{-(\tau_{\dot{h}_{eq}} s)}}{T_{\dot{h}_{eq}} s + 1}$$

The equivalent system parameters shall be obtained using the time domain fitting method defined below. The coefficient of determination, r^2, shall be greater than 0.97 and less than 1.03 for compliance with this requirement.

Obtain readings ft/sec from response to step collective input at intervals of no greater than t = 0.05 sec for a time span of 5 sec – a total of n = 5/Δt + 1 data points (minimum n = 101).

Use a three variable nonlinear least squares algorithm to obtain a best fit curve to this data in the time domain using the following form for the estimated $\dot{h}\left(\dot{h}_{est}\right)$

$$\dot{h}_{est}(t) = K\left[1-\exp\left[-(t-\tau_{\dot{h}_{eq}})/T_{\dot{h}_{eq}}\right]\right] \qquad \text{for } t > 0$$

where t is time (sec) and K, $1/T_{\dot{h}_{eq}}$ and $\tau_{\dot{h}_{eq}}$ are the variables. (Note: $\tau_{\dot{h}_{eq}}$ may be less than zero.)

The function to be minimized is the sum of squares of the error (e), defined as,

$$e^2 = \sum_{i=1}^{n}\left[\dot{h}(t=t_i) - \dot{h}_{est}(t=t_i)\right]^2$$

where t_i is the time (sec) at the ith observed data point.

The goodness of fit of the estimated curve shall be determined by the coefficient of determination (r^2) which is defined as

$$r^2 = \frac{\sum_{i=1}^{n}\left[\dot{h}_{est}(t=t_i) - \dot{h}_m\right]^2}{\sum_{i=1}^{n}\left[\dot{h}(t=t_i) - \dot{h}_m\right]^2}$$

where $\dot{h}_m$ is the mean of the observed $\dot{h}$, $\quad \dot{h}_m = \sum_{i=1}^{n}\frac{\dot{h}(t=t_i)}{n}$

3.3.9.2 Torque response

Torque, or any other parameter displayed to the pilot as a measure of the maximum allowable power that can be commanded without exceeding engine or transmission limits, shall have dynamic response characteristics that fall within the limits specified in Figure 16. This requirement shall apply if the displayed parameter must be manually controlled by the pilot to avoid exceeding displayed limits.

3.3.9.3 Vertical axis control power

From a spot OGE hover with the wind vector from the most critical speed and direction at a velocity of up to 35 knots, and with the most critical loading and density altitude, for Level 1 it shall be possible to achieve a vertical rate of at least 160 ft/min, 1.5 seconds after initiation of a rapid displacement of the collective control from trim. The minimum vertical rates shall be 55 ft/min for Level 2 and 40 ft/min for Level 3. Pitch, roll, and heading shall be maintained essentially constant. Applicable engine and transmission limits shall not be exceeded.

3.3.9.4 Short-term vertical rate response to disturbance inputs

If the system has a Vertical Rate Response-Type as defined in 3.2.10, the vertical rate response to disturbance input as defined in Figure 7 shall meet the limits specified in Table V, where the Disturbance Rejection Bandwidth (DRB) and Peak (DRP) parameters shall be obtained from frequency responses as defined in Figure 8.

3.3.9.5 Short-term height response to disturbance inputs

If Altitude (Height) Hold is specified as a required Response-Type in 3.2.2 and the system meets the Character of Vertical Rate Command with Altitude (Height) Hold requirement in 3.2.10.1, the altitude response to disturbance input as defined in Figure 7 shall meet the limits specified in Table V, where the Disturbance Rejection Bandwidth (DRB) and Peak (DRP) parameters shall be obtained from frequency responses as defined in Figure 8.

3.3.9.6 Rotor RPM governing

The rotor RPM shall remain within the limits set by the Service Flight Envelopes during the execution of all Mission-Task-Elements specified in 3.1.1 conducted within the Operational Flight Envelopes.

3.3.10 Position Hold

This requirement shall apply when Position Hold is a required Response-Type. When Position Hold is engaged, the rotorcraft shall automatically hold its position with respect to a ground fixed or shipboard hover reference. The rotorcraft shall maintain its position within a 10 ft diameter circle during a 360 degree turn in a steady wind of up to 15 knots. The 360-degree turn shall be accomplished by the use of the directional controller with the pitch and roll controllers free and collective control as required to maintain constant altitude. The maneuver shall be completed in less than 10 seconds if Aggressive agility is required, 30 seconds if only Moderate agility is required and 45 seconds for Limited agility. The pitch and roll attitudes shall not exceed ±18 degrees from trim at any point in the 360-degree turn. The command response shall meet the applicable response type, for example, TRC with PH shall meet the TRC response requirements. There shall be a clear annunciation to the pilot indicating status of the Position Hold function.

3.3.10.1 Short-term position response to disturbance

If Positon Hold is specified as a required Response-Type in 3.2.2 and the system meets the Position Hold requirement in 3.3.10, the position response to disturbance input as defined in Figure 7 shall meet the limits specified in Table V, where the Disturbance Rejection Bandwidth (DRB) and Peak (DRP) parameters shall be obtained from frequency responses as defined in Figure 8.

3.3.11 Translational Rate Response-Type

For Response-Types designated as Translational Rate Command, the translational rate response to step cockpit pitch (roll) control position or force inputs shall have a qualitative first order appearance, and shall have an equivalent rise time, $T_{\dot{x}_{eq}}$ ($T_{\dot{y}_{eq}}$), no less than 2.5 seconds and no greater than 5 seconds. The parameter $T_{\dot{x}_{eq}}$ ($T_{\dot{y}_{eq}}$) is defined in Figure 17a. For Level 1, the following requirements shall apply:

a. The pitch and roll attitudes shall not exhibit objectionable overshoots in response to a step cockpit controller input.

b. Zero cockpit control force and deflection shall correspond to zero translational rate with respect to fixed objects, or to the landing point on a moving ship.

c. There shall be no noticeable overshoots in the response of translational rate to control inputs. The gradient of translational rate with control input shall be smooth and continuous.

In addition, for centerstick controllers, the variation in translational rate with control deflection should lie within the limits of Figure 17b. For sidestick controllers, the variation in translational rate with control force should lie within the limits of Figure 17c. If the above TRC control sensitivities are not met, it is recommended that the Hover, Pirouette, Depart/Abort, and Lateral Reposition MTEs be flown and if the pilots do not object to the control sensitivities, a request for deviation from the recommended sensitivities is warranted.

3.3.11.1 Short-term translational rate response to disturbance

If Translation Rate Command is specified as a required Response-Type in 3.2.2 and the system meets the Character of Translational Rate Response-Type requirement in 3.2.9, the translational rate response to disturbance input as defined in Figure 7 shall meet the limits specified in Table V, where the Disturbance Rejection Bandwidth (DRB) and Peak (DRP) parameters shall be obtained from frequency responses as defined in Figure 8.

3.3.12 Pitch (Roll) response to externally slung loads

With an externally slung load, the baseline closed-loop bandwidth HQRs plus the delta HQR obtained from Figure 18 shall be Level 1 for load mass ratios less than 0.25, and shall not degrade to worse than 4.0 for load mass ratios up to 0.30. The load bandwidth ($\omega_{BW\text{-}LD}$) and delta dB (Δ_{dB}) parameters shall be obtained from the baseline and externally loaded pitch (roll) attitude frequency responses as defined in Figure 19.

Baseline is the pitch (roll) attitude frequency response of the aircraft internally loaded to the same gross weight as the aircraft plus the externally slung load.

$\omega_{BW\text{-}LD}$ is the lesser of -135 deg crossing *or* frequency of minimum phase due to the load mode.

Δ_{dB} is the deformation of magnitude curve due to externally slung load, estimated from centroid as follows:

a. Define area between frequency responses:
   - Determine the minimum and maximum frequency for the area by finding the intersections of the two frequency responses closest to the load mode freq. (or the load mode freq. +/- 0.2 rad/s if crossings exceed load mode freq. +/- 0.2 rad/s
   - Calculate the area strictly under the curve between these frequencies

b. Calculate centroid from: centroid = $\frac{\sum_{i=1}^{n} dA_i * y_i}{A}$

c. Rate command Δ_{dB}: pitch Δ_{dB} = 4*centroid, roll Δ_{dB} = 3*centroid

   Attitude command Δ_{dB}: pitch Δ_{dB} = 3*centroid, roll Δ_{dB} = 3*centroid

3.4 Forward flight requirements

The forward flight requirements shall apply throughout the applicable portions of the Operational and Service Flight Envelopes for operations at greater than 45 knots groundspeed.

3.4.1 Pitch attitude response to longitudinal controller

3.4.1.1 Short-term response (bandwidth)

The pitch attitude response to longitudinal cockpit control position inputs shall meet the limits specified in Figure 20. The bandwidth (ω_{BW_θ}) and phase delay (τ_{p_θ}) parameters shall be obtained from frequency responses as defined in Figure 6. It is desirable to also meet this criterion for controller force inputs. If the bandwidth for force inputs falls outside the specified limits, flight testing shall be conducted to determine that the force feel system is not excessively sluggish. For Attitude Command Response-Types, if the bandwidth defined by gain margin is less than the bandwidth defined by phase margin, or is undefined, the rotorcraft may be PIO prone. In this case flight testing shall be performed to determine acceptability.

3.4.1.2 Mid-term response to control inputs

The mid-term response characteristics shall apply at all frequencies and for oscillations of all magnitudes that are noticeable to the pilot. Use of an Attitude Hold Response-Type shall constitute compliance with this requirement, as long as any oscillatory modes following a pulse controller input have an effective damping ratio of at least $\zeta = 0.35$. If Attitude Hold is not available, the applicable criterion shall depend on the degree of pilot attention according to 3.1.3. The lack of oscillations implies compliance.

3.4.1.2.1 Fully attended operations

The mid-term response shall meet the requirements of Figure 9.

3.4.1.2.2 Divided attention operations

The limits of Figure 9 shall be met, except that the Level 1 damping ratio shall not be less than $\zeta = 0.35$ at any frequency.

3.4.1.3 Mid-term response – maneuvering stability

The following maneuvering stability requirements shall apply at all airspeeds greater than 45 knots.

3.4.1.3.1 Control feel and stability in maneuvering flight at constant speed

In steady turning flight at constant airspeed, and in pullups and pushovers, for Levels 1 and 2 there shall be no tendency for the rotorcraft pitch attitude or angle of attack to diverge aperiodically. For the above conditions, the incremental control force required to maintain a change in normal load factor and pitch rate shall be in the same sense (aft force – more positive load factor, forward force – more negative load factor) as those required to initiate the change. These requirements shall apply for all local gradients.

3.4.1.3.2 Control forces in maneuvering flight

The variations in longitudinal cockpit control force with steady-state normal acceleration shall have no objectionable nonlinearities throughout the Operational Flight Envelope. At no time shall a negative local gradient be permitted. In addition, deflection of the longitudinal cockpit controller shall not lead the control force at any frequency below 5 rad/sec. For Level 1 the following requirements shall apply:

a. For centerstick controllers, the local force gradient, Fs/n, shall be at least 3 lb/g and no greater than 15 lb/g.
b. For sidestick controllers, the local force gradient shall be at least 3 lb/g and no greater than 6 lb/g.
c. The local slope of Fs vs. n should be relatively constant over the range of normal accelerations within the Operational Flight Envelopes. A variation of more than 50 percent shall be considered as excessive.

3.4.2 Pitch control power

For Level 1, from trimmed, unaccelerated flight the rotorcraft shall achieve the load factor limits specified in the Operational Flight Envelopes during turns or pull-up/push-over maneuvers.

For Level 2, the following requirements shall apply:

a. There shall be sufficient pitch control authority to accelerate from 45 knots to the maximum level flight airspeed, and to decelerate back to 45 knots at constant altitude.
b. Sufficient pitch authority shall be available to maintain altitude if full power is applied at 45 knots and if minimum power is applied at maximum level flight airspeed.

3.4.3 Flight path control

When operating at airspeeds on the frontside of the power required curve, 3.4.3.1 shall apply. For operation at airspeeds on the backside of the power required curve, or when 3.4.3.1 cannot be met, 3.4.3.2 shall apply. For the purpose of this requirement, frontside operation shall be defined when the slope of the steady-state response of flight path angle vs. airspeed, $\Delta\gamma_{ss}/\Delta V_{ss}$, resulting from a step change in pitch attitude, with collective held fixed, is negative. Backside operation shall be defined when this slope is positive or zero.

3.4.3.1 Flight path response to pitch attitude (frontside)

The vertical rate response shall not lag the pitch attitude response, with the collective controller held fixed, by more than 45 degrees at all frequencies below 0.40 rad/sec for Level 1 and 0.25 rad/sec for Level 2.

3.4.3.2 Flight path response to collective controller (backside)

The vertical rate response shall have a qualitative first-order appearance for at least 5 seconds following a step collective input. Pitch attitude excursions shall be limited so that they have a negligible effect on the vertical rate response. The limits on the parameters defined by the following equivalent first-order vertical-rate-to-collective transfer function shall be in accordance with the values specified in Table VIII. The equivalent system parameters are to be obtained using the time domain fitting method defined in

3.3.9.1. The coefficient of determination, r^2, shall be greater than 0.97 and less than 1.03 for compliance with this requirement.

$$\frac{\dot{h}}{\delta_c} = \frac{K e^{-(\tau_{\dot{h}_{eq}} s)}}{T_{\dot{h}_{eq}} s + 1}$$

3.4.3.3 Rotor RPM governing

The rotor RPM shall remain within the limits set by the Service Flight Envelopes during the execution of all Mission-Task-Elements specified in 3.1.1 conducted within the Operational Flight Envelopes.

3.4.4 Longitudinal static stability

Push (pull) force on the longitudinal controller shall always be required to increase (decrease) speed. Without retrimming, steady state changes in controller force for increased (decreased) speed shall be push (pull) or zero. Meeting the requirements for pitch Attitude Command in Section 3.2.8 constitutes compliance with longitudinal static stability in this specification.

3.4.5 Roll attitude response to lateral controller

3.4.5.1 Small-amplitude roll attitude response to control inputs (bandwidth)

The roll attitude response to lateral cockpit control position inputs shall meet the limits specified in Figure 21. The bandwidth (ω_{BW_ϕ}) and phase delay (τ_{p_ϕ}) parameters shall be obtained from frequency responses as defined in Figure 6. It is desirable to also meet this criterion for controller force inputs. If the bandwidth for force inputs falls outside the specified limits, flight testing shall be conducted to determine that the force feel system is not excessively sluggish. For Attitude Command Response-Types, if the bandwidth defined by gain margin is less than the bandwidth defined by phase margin, or is undefined, the rotorcraft may be PIO prone. In this case flight testing shall be performed to determine acceptability.

3.4.5.2 Moderate amplitude attitude changes (attitude quickness)

The ratio of peak roll rate to change in bank angle, $p_{pk}/\Delta\phi_{pk}$, shall meet the limits specified in Figure 22. The required attitude changes shall be made as rapidly as possible from one steady attitude to another without significant reversals in the sign of the cockpit control input relative to the trim position. The attitude changes required for compliance with this requirement shall vary from 10 deg to the limits of the Operational Flight Envelope or 60 deg, whichever is less. The parameters in Figure 22 are defined in Figure 10.

3.4.5.3 Large-amplitude roll attitude changes

The achievable roll rate (for Rate Response-Types) or attitude change from trim (for Attitude Response-Types) shall be at least those specified in Table IX. Yaw control may be used to reduce sideslip that retards roll rate (not to produce sideslip that augments roll rate).

3.4.6 Roll-sideslip coupling

The requirements on roll-sideslip coupling shall apply for both right and left lateral control commands of all magnitudes up to the magnitude required to meet the roll performance requirements of 3.4.5.2. The cockpit yaw controller shall be free. The parameters defined in Figure 23 shall be used.

3.4.6.1 Bank angle oscillations

The value of the parameter ϕ_{OSC}/ϕ_{AV} following a pulse lateral control command for Rate Response-Types or step command for Attitude Response-Types shall be within the limits specified in Figure 24 for Levels 1 and 2. The input shall be as abrupt as practical. For Levels 1 and 2, ϕ_{AV} shall always be in the direction of the lateral control command.

3.4.6.2 Turn coordination

The amount of sideslip resulting from abrupt lateral control commands shall not be excessive or require complicated or objectionable directional control coordination. The ratio of the maximum change in sideslip angle to the initial peak magnitude in roll response, $\left|\Delta\beta/\phi_1\right|$, for an abrupt lateral control pulse command for Rate Response-Types or step command for Attitude Response-Types, shall not exceed the limit specified on Figure 25. In addition, if the ratio $\left|\phi/\beta\right|_d$ exceeds 0.20, the product $0.20\times\left|\Delta\beta/\phi_1\right|\times\left|\phi/\beta\right|_d$ shall not exceed the limit specified on Figure 25.

3.4.7 Yaw response to yaw controller

3.4.7.1 Small-amplitude yaw response (bandwidth)

The heading response to cockpit yaw control position inputs shall meet the limits specified in Figure 26. The bandwidth (ω_{BW_ψ}) and phase delay (τ_{p_ψ}) parameters shall be obtained from frequency responses as defined in Figure 6. It is desirable to also meet this criterion for controller force inputs. If the bandwidth for force inputs falls outside the specified limits, flight testing shall be conducted to determine that the force feel system is not excessively sluggish.

3.4.7.2 Large-amplitude heading changes for Aggressive agility

The heading change in 1 second following an abrupt step displacement of the yaw control shall not be less than:

Level 1: the lesser of 16 degrees or β_L

Level 2: the lesser of 8 degrees or 1/2 β_L

Level 3: the lesser of 4 degrees or 1/4 β_L

where β_L is the sideslip limit of the Operational Flight Envelope in degrees. Other controls should be fixed but may be used to reduce pitch and roll attitude excursions.

3.4.7.3 Yaw control with speed change

With the rotorcraft initially trimmed directionally, yaw control shall be sufficient to maintain heading constant with the yaw controller, at constant bank angle, when speed is rapidly increased or decreased 30 percent from the trim speed or 20 knots, whichever is less (except where limited by the boundaries of the Service Flight Envelope). For pedal controllers, the yaw control forces shall not be greater than one-half those of Table XIV. For other yaw control types, the forces required shall not be objectionable to the pilot. These requirements shall be satisfied without retrimming and accomplished at constant power (altitude varies), and at constant altitude (power varies).

3.4.8 Lateral-directional stability

3.4.8.1 Lateral-directional oscillations

The frequency, ω_n, and damping ratio, ζ, of the lateral-directional oscillations following a yaw control doublet, shall meet the minimums specified on Figure 27. This requirement shall also be met for a roll control pulse input. The requirements shall be met with controls fixed and with them free for inputs of any magnitude that might be experienced in operational use. If the oscillation is nonlinear with amplitude, the requirements shall apply to each cycle of the oscillation. The lack of oscillations implies compliance.

3.4.8.2 Spiral stability

Following a lateral pulse control input, the time for the bank angle to double amplitude shall be greater than the following:

Level 1: 20.0 seconds

Level 2: 12.0 seconds

Level 3: 4.0 seconds

These requirements shall be met with the cockpit controls free and the rotorcraft trimmed for straight and level flight. The values specified apply to an exponential divergence and should not depend on the size of the control input. If the variation of roll angle with time is linear following the pulse control input, this requirement is satisfied.

3.4.9 Lateral-directional characteristics in steady sideslips

The requirements of 3.4.9.1 through 3.4.9.3.1 shall be met while performing yaw-control-induced, steady zero-yaw-rate sideslips in the worst flight condition with the rotorcraft trimmed for straight flight.

3.4.9.1 Yaw control in steady sideslips (directional stability)

For the sideslips specified in 3.4.9, right yaw control deflection and force shall be required in left sideslips and left yaw control deflection and force shall be required in right sideslips. For Levels 1 and 2, the following requirements shall apply. Between sideslip angles of ±15 degrees, or the sideslip limit of the Operational Flight Envelopes, whichever is less, the variation of yaw controller deflection and force shall be essentially linear with sideslip. For larger sideslip angles, an increase in yaw control deflection shall always be required for an increase in sideslip, and the following requirements shall apply:

Level 1: The gradient of sideslip angle with yaw control force shall not reverse slope.

Level 2: The gradient of sideslip angle with yaw control force is permitted to reverse slope provided the sign of the yaw control force does not reverse.

The term gradient does not include that portion of the yaw control force versus sideslip-angle curve within the preloaded breakout force or friction band.

3.4.9.2 Bank angle in steady sideslips

For the sideslips specified in 3.4.9, an increase in right bank angle shall accompany an increase in right sideslip, and an increase in left bank angle shall accompany an increase in left sideslip.

3.4.9.3 Lateral control in steady sideslips

For the sideslips specified in 3.4.9, right (left) sideslips shall not require left (right) lateral control deflection or force. For Levels 1 and 2, the variation of lateral control deflection and force with sideslip angle shall be essentially linear.

3.4.9.3.1 <u>Positive effective dihedral limit</u>

For Level 1, positive effective dihedral (right roll control for right sideslip and left roll control for left sideslip) shall never be so great that more than 75 percent of the roll control power available to the pilot and no more than 11 pounds of roll control force (for centerstick controllers) are required for sideslip angles that might be experienced in performing the required Mission-Task-Elements. The corresponding limits for Level 2 shall be 90 percent and 13.5 pounds.

3.4.10 Interaxis coupling

Control inputs in one axis shall not result in objectionable responses in one or more of the other axes while performing any of the Mission-Task-Elements specified in 3.1.1.

3.4.10.1 Pitch attitude due to collective control

3.4.10.1.1 <u>Small collective inputs</u>

The peak change in pitch attitude from trim, , occurring within the first 3 seconds following a step change in collective causing less than 20% torque change, shall be such that the ratio is no greater than 1.0 deg/ft/sec^2, where is the peak incremental normal acceleration from 1 g flight.

3.4.10.1.2 <u>Large collective inputs</u>

The peak change in pitch attitude from trim, , occurring within the first 3 seconds following a step change in collective causing greater than or equal to 20% torque change shall be such that the ratio is no greater than 0.5 deg/ft/sec^2 in the up direction and 0.25 deg/ft/sec^2 in the down direction.

3.4.10.1.3 Pitch control in autorotation
During an autorotation to touchdown from any point in the Operational Flight Envelopes, there shall be at least 10 percent of the total (stop-to-stop) pitch controller effectiveness remaining throughout the maneuver.

3.4.10.2 Roll due to pitch coupling for Aggressive agility
The ratio of peak roll attitude response from trim within 4 seconds to the desired pitch attitude response from trim at 4 seconds, , following an abrupt longitudinal cockpit control step input, shall not exceed ±0.25 for Level 1 or ±0.60 for Level 2. Heading shall be maintained essentially constant.

3.4.10.3 Pitch due to roll coupling for Aggressive agility
The pitch response resulting from bank to bank maneuvering with collective held fixed, and the yaw controller used as necessary to achieve turn coordination, shall not be objectionable to the pilot.

3.4.10.4 Pitch due to roll and roll due to pitch coupling for Target Acquisition and Tracking
The pitch due to roll (q/p) and roll due to pitch (p/q) coupling for Target Acquisition and Tracking shall not exceed the limits specified in Figure 14. The average q/p and average p/q are derived from ratios of pitch and roll frequency responses. Specifically, average q/p is defined as the magnitude of pitch-due-to-roll control input (q/δ_{lat}) divided by roll-due-to-roll control input (p/δ_{lat}) averaged between the bandwidth and neutral-stability (phase = -180 deg) frequencies of the pitch-due-to-pitch control inputs (θ/δ_{lon}). Similarly, average p/q is defined as the magnitude (p/δ_{lon}) divided by (q/δ_{lon}) between the roll-axis (ϕ/δ_{lat}) bandwidth and neutral stability frequencies. Off-axis inputs shall be minimized while generating the frequency response data. Multi-input/multi-output frequency response identification techniques shall be used to analyze the frequency responses to account for the effect of inadvertent multiple-axis control inputs which may have been present during the excitation.

3.4.11 Pitch, roll, and yaw responses to disturbance inputs
If Attitude Hold / Heading (Direction) Hold is specified as a required Response-Type in 3.2.2 and the system meets the Character of Attitude / Heading Hold Response-Type requirement in 3.2.7, the attitude / heading response to disturbance input as defined in Figure 7 shall meet the limits specified in Table X, where the Disturbance Rejection Bandwidth (DRB) is calculated as frequency at which the sensitivity function of the hold variable crosses -3 dB and Disturbance Rejection Peak (DRP) is defined as the peak magnitude of the sensitivity function of the hold variable. The DRB and DRP parameters shall be obtained from frequency responses as defined in Figure 8.

3.5 Transition of a variable configuration rotorcraft between rotor-borne and wing-borne flight
This paragraph is reserved for future requirements.

3.6 Controller characteristics

3.6.1 Conventional controllers

3.6.1.1 Centering and breakout forces
Pitch, roll, and yaw controls shall exhibit positive centering in flight at any normal trim setting. The combined effects of centering, breakout force, stability, and force gradient shall not produce objectionable flight characteristics or permit noticeable departures from trim conditions with controls free. Breakout forces, including friction, preload, etc., refer to the cockpit control force required to start movement of the control surface in flight. The breakout forces shall be within the limits specified in Table XI for hover and low speed and Table XII for forward flight. The change in breakout force with speed shall not be objectionable. Measurement of breakout forces on the ground will ordinarily suffice in lieu of actual flight

measurement, provided qualitative agreement between ground measurement and flight observation can be established.

3.6.1.2 Force gradients

The pitch, roll, and yaw control force gradients shall be within the range specified in Table XIII throughout the range of control deflections. In addition, the force produced by a one-inch travel from trim by the gradient chosen shall not be less than the breakout force. For the remaining control travel, the local gradients shall not change by more than 50 percent in one inch of travel. The thrust magnitude control shall preferably have zero force gradient unless an autothrottle function such as Height Hold, or envelope cueing, is active.

3.6.1.3 Limit control forces

Unless otherwise specified in particular requirements, the maximum control forces required, without retrimming, for any maneuver consistent with the specified Mission-Task-Elements (3.1.1) shall not exceed the values stated in Table XIV.

3.6.1.4 Active Inceptor cyclic dynamic characteristics

Active Inceptor Systems are defined as a class of pilot cockpit controllers that include a programmable servo-actuator controlled force-feel system. The pitch and roll controller damping and natural frequency shall meet the requirements specified in Figure 28.

3.6.2 Sidestick controllers

This paragraph is reserved for future requirements.

3.6.3 Sensitivity and gradients

The pitch, roll, yaw, and collective controller sensitivities and gradients shall be consistent with the rotorcraft dynamic response characteristics in each axis at all flight conditions. In no case shall the controller sensitivity or gradient produce responses that are objectionably abrupt or sluggish.

3.6.4 Cockpit control free play

The free play in each control, that is, any motion of the cockpit control that does not move the appropriate moment- or force-producing device in flight, shall not be objectionable.

3.6.5 Control harmony

The control forces, displacements, and sensitivities of the pitch, roll, yaw, and collective controls shall be compatible, and their responses shall be harmonious.

3.6.6 Trimming characteristics

It shall be possible to trim controller forces to zero for all unaccelerated flight conditions. Actuation of the trim device to null controller force shall not produce an objectionable change in rotorcraft attitude or translational rate. Operation of the trimmers shall not require a force that is objectionably low or high. The trimmer shall not produce objectionable stick jump, trim rates, or slippage in the trim control position.

3.6.7 Dynamic coupling

There shall be no tendency for dynamic coupling between the rotorcraft and the controller with or without the pilot in the loop. In particular, there shall be no lightly damped, high frequency oscillations that cease when the pilot releases the controller.

3.7 Transfer between Response-Types

The transients and trim changes caused by the intentional transfer between Response-Types shall not be objectionable.

3.7.1 Annunciation of Response-Type to the pilot

If more than one Response-Type can be selected in a given axis, there shall be a clear and easily interpretable annunciation to the pilot indicating which of the Response-Types are currently engaged or armed. For near-earth operations, the annunciation shall be located so that it is not necessary for the pilot to significantly shift his eye point of regard from the forward near-field or to look around, or refocus any vision aid.

3.7.2 Control forces during transfer

Following transfer between Response-Types, control forces required to suppress transients shall not exceed one-third of the appropriate limit control forces in Table XIV. The rotorcraft shall initially be trimmed at a fixed operating point, and during the transfer the heading, altitude, rate of climb or descent, and speed shall be maintained without use of the trimmer controls. For blending, the limit forces shall apply over the time interval specified in 3.7.3 following completion of the pilot action initiating the blend. There shall be no objectionable buffeting or oscillations of the control device during the blend.

3.7.3 Control system blending

Blending between Response-Types shall be essentially linear with time and shall occur within the time limitations specified below.

Blending During Deceleration: 2 sec < t_{blend} < 10 sec

Blending During Acceleration: 2 sec < t_{blend} < 5 sec

When blending from a series to a parallel trim system, a longitudinal or directional trim follow-up may be used as long as the cockpit controller does not move more than 20 percent of its travel in either direction during the blend.

3.8 Ground handling and ditching characteristics

Flight control system and landing gear characteristics shall allow takeoff, landing, and required ground maneuvers to be performed without excessive pilot workload or objectionable characteristics. In particular, the following capabilities shall be provided as required by the system specification.

3.8.1 Rotor start/stop

It shall be possible, while on the ground, to start and stop the rotor blades in mean winds up to at least 45 knots from the most critical direction. It shall be possible, while on a flight deck, to start and stop the rotor blades within the relative winds and flight deck vertical and lateral accelerations defined in the shipborne helicopter operating limits.

3.8.1.1 Shipboard operation

It shall be possible to bring the engines to idle power without engaging the rotor(s), and to stop the blades within 20 seconds after engine shutdown within the relative winds and flight deck vertical and lateral accelerations defined in the shipborne helicopter operating limits.

3.8.2 Parked position requirement

It shall be possible, without the use of wheel chocks or skid restraints, to maintain a fixed position on a level paved surface at the normal takeoff rotor speed as power is increased prior to lift-off.

3.8.3 Wheeled rotorcraft ground requirements

The following ground handling conditions shall be met for all operational weather conditions.

a. It shall be possible, without the use of brakes, to maintain a straight path while taxiing or performing rolling takeoffs or landings in a wind of up to 45 knots from any direction.

b. It shall be possible to make complete 360-degree turns in either direction by pivoting on either main landing gear in a wind of up to 45 knots from any direction. These turns shall be made within a radius equaling the major dimension of the rotorcraft.

c. It shall be possible to perform all required maneuvers, including taxiing, rolling takeoffs and landings, and pivoting, without damage to rotor stops and without contact between the main rotor or tail rotor blades and any part of the rotorcraft structure.

3.8.4 Ditching characteristics

The following characteristics shall be provided either as part of the rotorcraft design or in supplementary kit form. The system specification will specify the range of sea states for which the characteristics must be provided.

3.8.4.1 Water landing requirement

In both power-ON and power-OFF autorotative conditions, it shall be possible to make a safe landing on smooth water up to at least 20 knots surface speed with an 8 ft/sec rate of descent and at least 30 knots with a 5 ft/sec rate of descent at angles of yaw up to 15 degrees.

3.8.4.2 Ditching techniques

Attitude and airspeed conditions shall be established for ditching the rotorcraft on water in the event of:

a. The loss of all engine power.

b. The failure of one engine.

Ditching shall not cause immediate injury to the occupants, or make it impossible to exit the rotorcraft through the emergency exits (i.e., due to an adverse static water level on the cabin emergency exits or the blocking of emergency exits by all or part of the flotation system).

3.8.4.3 Flotation requirements

The flotation time and trim attitude characteristics of the rotorcraft shall be such that the crew and passengers are provided with a sufficient length of time to exit the rotorcraft safely and to enter life rafts without application of a rotor brake, sea anchor, or similar device. A sea anchor may be used to assist in deployment of life rafts.

3.8.4.4 Single failures of the flotation equipment

The flotation time and trim attitude requirements of 3.8.4.3 shall also be met with the most critical compartment of the flotation system inoperative (i.e., as caused by a leak deflating the compartment or a failure in actuation of the inflation mechanism).

3.9 Requirements for externally slung loads

3.9.1 Load release

The rotorcraft shall be capable of safely jettisoning external loads from any condition within the External Loads Service Flight Envelope.

3.9.2 Failure of external load system

Within the External Loads Service Flight Envelope, any single failure of a suspension system element (including attachment fittings, slings, pendants, apex fittings, and cargo hooks) shall not result in loss of control of the rotorcraft or cause substantial damage to the airframe. When crew members have the capability to monitor and jettison the load in a fully attended manner, a 1.0 second failure recognition delay time shall be considered when evaluating crew initiated jettison scenarios.

3.10 Mission-Task-Elements

A selection of flight test maneuvers are provided in the form of precisely defined Mission-Task-Elements (MTEs). All MTEs designated by 3.1.1 shall be accomplished. These MTEs provide a basis for an overall assessment of the rotorcraft's ability to perform certain critical tasks, and result in an assigned level of HQ (3.1.5.2). To allow for different standards of precision and aggressiveness, the performance standards for each task are listed separately for different rotorcraft categories and for both Good Visual Conditions (GVE) and Degraded Visual Conditions (DVE). Generally, GVE means clear daylight with good cueing and unaided vision (UCE=1). DVE means specifically the operational environment defined in 3.1.1. Typically, DVE will be night with some level of illumination (moon and overcast) while using the actual mission equipment vision aid (UCE>1).

Conduct of tests. The applicable MTEs shall be performed with all combinations of manual flight control modes and displays available to the pilot and used as they would normally be used in the conduct of the maneuver. Altitude and position requirements refer to a selected reference point on the rotorcraft that is to be determined by the testing activity. Generally, this should be close to the pilot's eye point, but for small rotorcraft the Hovering Turn and Turn to Target may be performed about the center of gravity. All altitudes given are above ground level. A description of a suggested test course is provided for each maneuver. However, the test course markings and detail are left to the discretion of the testing activity. The terms "calm winds," "moderate winds," "stabilized hover," and "landing gear" are defined in 6.2.

Each MTE shall be assessed by at least three pilots. These pilots shall each assign a subjective rating using the Cooper-Harper Handling Qualities Rating scale (Figure 1). The arithmetic average across all pilots of the Cooper-Harper Handling Qualities Ratings forms the overall rating for the MTE. All individual ratings and associated evaluation commentary shall be documented and supplied to the Government. The maneuvers shall be performed to assess the rotorcraft in configurations and states that are most critical for handling qualities in accordance with Section 4.0 Verification.

Performance standards. The use of Cooper-Harper Handling Qualities Ratings requires the definition of numerical values for desired and adequate performance. These performance limits are set primarily to drive the level of aggressiveness and precision to which the maneuver is to be performed. Compliance with the performance standards may be measured subjectively from the cockpit or by the use of ground observers. It is not necessary to utilize complex instrumentation for these measurements. Experience has shown that lines painted on the rotorcraft and markers on the ground are adequate to provide sufficient cues for ground or onboard observers to perceive whether the rotorcraft is within desired or adequate performance parameters. In any event, the contractor shall develop a scheme for demonstrating compliance that uses at least outside observers and in-cockpit observations. This plan will be subject to approval by the Government. The evaluation pilot is to be advised any time his performance fails to meet the desired limits, immediately following the completion of the maneuver, and before the pilot rating is assigned. In cases where the performance does not meet the specified limits, it is acceptable for the evaluation pilot to make as many repeat runs as necessary to insure that this is a consistent result. Repeat runs to improve performance may expose handling qualities deficiencies. Such deficiencies should be an important factor in the assigned pilot rating.

Visual cueing. If the inability to meet a performance standard in GVE is due to a lack of visual cueing, the test course should be modified to provide the required pilot cues. This is allowed in the context that the purpose of these maneuvers is to check rotorcraft handling, not problems associated with a lack of objects on the test course. To accommodate different performance standards the test courses may be modified to conduct the DVE maneuvers. If additional modifications in visual cueing are required to enhance the visual cues in the DVE, the changes shall be defined and submitted to the Government for approval prior to testing.

3.10.1 Hover

a. Objectives.

- Check ability to transition from translating flight to a stabilized hover with precision and a reasonable amount of aggressiveness.
- Check ability to maintain precise position, heading, and altitude in the presence of a moderate wind from the most critical direction in the GVE; and with calm winds allowed in the DVE.

b. Description of maneuver. Initiate the maneuver at a ground speed of between 6 and 10 knots, at an altitude less than 20 ft. For rotorcraft carrying external loads, the altitude will have to be adjusted to provide a 10 ft load clearance. The target hover point shall be oriented approximately 45 degrees relative to the heading of the rotorcraft. The target hover point is a repeatable, ground-referenced point from which rotorcraft deviations are measured. The ground track should be such that the rotorcraft will arrive over the target hover point (see illustration in Figure 29). In the GVE, the maneuver shall be accomplished in calm winds and in light winds from the most critical direction. If a critical direction has not been defined, the hover shall be accomplished with the wind blowing directly from the rear of the rotorcraft.

c. Description of test course. The suggested test course for this maneuver is shown in Figure 29. Note that the hover altitude depends on the height of the hover sight and the distance between the sight, the hover target, and the rotorcraft. These dimensions may be adjusted to achieve a desired hover altitude.

d. Performance standards. Accomplish the transition to hover in one smooth maneuver. It is not acceptable to accomplish most of the deceleration well before the hover point and then to creep up to the final position.

Performance – Hover

	Scout/Attack		**Cargo/Utility**		**Externally Slung Load**	
	GVE	DVE	GVE	DVE	GVE	DVE
DESIRED PERFORMANCE						
• Attain a stabilized hover within X seconds of initiation of deceleration:	3 sec	10 sec	5 sec#	10 sec	10 sec	13 sec
• Maintain a stabilized hover for at least:	30 sec	30 sec	30 sec	30 sec	30 sec	30 sec
• Maintain the longitudinal and lateral position within ±X ft of a point on the ground:	3 ft	3 ft	3 ft	3 ft	3 ft	3 ft
• Maintain altitude within ±X ft:	2 ft	2 ft	2 ft	2 ft	4 ft	4 ft
• Maintain heading within ±X deg:	5 deg	5 deg	5 deg	5 deg	5 deg	5 deg
• There shall be no objectionable oscillations in any axis either during the transition to hover or the stabilized hover	✓*	✓	✓	✓	✓	N/A*
ADEQUATE PERFORMANCE						
• Attain a stabilized hover within X seconds of initiation of deceleration:	8 sec	20 sec	8 sec#	15 sec	15 sec	18 sec
• Maintain a stabilized hover for at least:	30 sec	30 sec	30 sec	30 sec	30 sec	30 sec
• Maintain the longitudinal and lateral position within ±X ft of a point on the ground:	6 ft	6 ft	6 ft	6 ft	6 ft	6 ft
• Maintain altitude within ±X ft:	4 ft	4 ft	4 ft	4 ft	6 ft	6 ft
• Maintain heading within ±X deg:	10 deg	10 deg	10 deg	10 deg	10 deg	10 deg

*Note: For all tables, ✓ = performance standard applies; N/A = performance standard not applicable

#Note: The Cargo-category requirements were based on CH-47 flight tests. Experience has shown that the 5- and 8-second times in the GVE should be expanded to 10- and 15-seconds for larger aircraft. Requests for these changes shall be defined and submitted to the Government for approval prior to testing.

3.10.2 Landing

a. Objectives.

- Check ability to precisely control the rotorcraft position during the final descent to a precision landing point.
- Check pilot-vehicle dynamics when pilot is forced into tight compensatory tracking behavior.

b. Description of maneuver. Starting from an altitude of greater than 10 ft, maintain an essentially steady descent to a prescribed landing point. It is acceptable to arrest sink rate momentarily to make last-minute corrections before touchdown.

c. Description of test course. This task may be performed using the hover course (Figure 29) with the designated landing point being directly under the reference point on the rotorcraft when the pilot's eye is at the hover point.

d. Performance standards.

Performance – Landing

	Scout/Attack		Cargo/Utility	
	GVE	DVE	GVE	DVE
DESIRED PERFORMANCE				
• Accomplish a gentle landing with a smooth continuous descent, with no objectionable oscillations	✓	N/A	✓	N/A
• Once altitude is below 10 ft, complete the landing within X seconds	10 sec	10 sec	10 sec	10 sec
• Touch down within ±X ft longitudinally of the designated reference point	1 ft	1 ft	3 ft	3 ft
• Touch down within ±X ft laterally of the designated reference point	0.5 ft	0.5 ft	2 ft	2 ft
• Attain a rotorcraft heading at touchdown that is aligned with the reference heading within ±X deg:	5 deg	5 deg	5 deg	5 deg
• Final position shall be the position that existed at touchdown. It is not acceptable to adjust the rotorcraft position and heading after all elements of the landing gear have made contact with the pad.	✓	✓	✓	✓
ADEQUATE PERFORMANCE				
• Touch down and remain within ±X ft of the designated landing point	3 ft	3 ft	3 ft	3 ft
• Attain a rotorcraft heading at touchdown that is aligned with the reference heading within ±X deg:	10 deg	10 deg	10 deg	10 deg

3.10.3 Slope Landing and Liftoff

a. Objectives.

- Check adequacy of any stability and control augmentation system changes that respond to partial or full landings.
- Check ability to precisely coordinate control of the heave axis and lateral axis with either the left or right part of the landing gear in contact with the ground.
- Check ability to precisely coordinate control of the heave axis and longitudinal axis with either the aft or forward part of the landing gear on the ground.

b. Description of maneuver. Perform a vertical landing to a sloped surface with the rotorcraft longitudinal axis oriented perpendicular to the fall line. Also perform vertical landings to a sloped surface with the rotorcraft longitudinal axis oriented parallel to the fall line. The landings shall be made with the nose pointed uphill and downhill, and with the up-slope to the left and right. For all of the slope landings, follow the following procedure. Once the upslope landing gear is in contact with the ground, maintain a level rotorcraft attitude for a short period of time, and then gently lower the downslope landing gear to the ground. Raise the downslope landing gear, keeping the upslope landing gear in contact with the ground, and maintain a level rotorcraft attitude for a short time before liftoff.

c. Description of test course. The test area shall consist of sloped terrain that is at least 75% of the rotorcraft slope landing performance limits. The landing area shall be clearly marked on the ground.

d. Performance standards.

Performance – Slope Landing and Liftoff

	GVE	DVE
DESIRED PERFORMANCE		
• Touch down and maintain a final position within an area that is X ft longer than the rotorcraft landing gear	6 ft	6 ft
• Touch down and maintain a final position within an area that is X ft wider than the rotorcraft landing gear	4 ft	4 ft
• Maintain heading within ±X deg:	5 deg	5 deg
• Maintain a level rotorcraft attitude with one part of the landing gear in contact with the ground and the rest in the air for at least X seconds before lowering and raising the downhill part of the landing gear	5 sec	5 sec
• No perceptible horizontal drift at touchdown or liftoff	✓	✓
• Any load limits shall remain within the OFE	✓	✓
ADEQUATE PERFORMANCE		
• Touch down and maintain a final position within an area that is X ft longer than the rotorcraft landing gear	12 ft	12 ft
• Touch down and maintain a final position within an area that is X ft wider than the rotorcraft landing gear	8 ft	8 ft
• Maintain heading within ±X deg:	10 deg	10 deg
• Maintain a level rotorcraft attitude with one part of the landing gear in contact with the ground and the rest in the air for at least X seconds before lowering and raising the downhill part of the landing gear	5 sec	5 sec
• No perceptible horizontal drift at touchdown or liftoff	✓	✓
• Any load limits shall remain within the OFE	✓	✓

3.10.4 Hovering Turn

a. Objectives.

- Check for undesirable handling qualities in a moderately aggressive hovering turn.
- Check ability to recover from a moderate rate hovering turn with reasonable precision.
- Check for undesirable interaxis coupling.
- In the DVE, check for undesirable display symbology and dynamics for hover.

b. Description of maneuver. From a stabilized hover at an altitude of less than 20 ft, complete a 180 degree turn. Perform the maneuver in both directions. For a cockpit with side-by-side seating, the evaluation pilot should be allowed to sit in either seat to assess potential detrimental cueing effects on the handling qualities rating. In the GVE, the maneuver shall be accomplished in calm winds and in light winds from the most critical direction. If a critical direction has not been defined, the turn shall be terminated with the wind blowing directly from the rear of the rotorcraft.

c. Description of test course. It is suggested that this maneuver use the test course described for the pirouette (Figure 30) with the rotorcraft located at the center of the pirouette circle. An alternate suggestion is to use the hover course with two extra markers placed in the 6 o'clock position relative to the rotorcraft. The maneuver begins with the rotorcraft lined up on these extra markers and the hover target and board located at the rotorcraft's 6 o'clock position.

d. Performance standards.

Performance – Hovering Turn

	Scout/Attack		**Cargo/Utility**	
	GVE	DVE	GVE	DVE
DESIRED PERFORMANCE				
• Maintain the longitudinal and lateral position within ±X ft of a point on the ground	3 ft	6 ft	3 ft	6 ft
• Maintain altitude within ±X ft:	3 ft	3 ft	3 ft	3 ft
• Stabilize the final rotorcraft heading at 180 deg from the initial heading within ±X deg:	3 deg	5 deg	5 deg	5 deg
• Complete turn to a stabilized hover (within the desired window) within X seconds from initiation of the maneuver	10 sec	15 sec	15 sec	15 sec
ADEQUATE PERFORMANCE				
• Maintain the longitudinal and lateral position within ±X ft of a point on the ground	6 ft	12 ft	6 ft	12 ft
• Maintain altitude within ±X ft:	6 ft	6 ft	6 ft	6 ft
• Stabilize the final rotorcraft heading at180 deg from the initial heading within ±X deg:	6 deg	10 deg	10 deg	10 deg
• Complete turn to a stabilized hover (within the adequate window) within X seconds from initiation of the maneuver	15 sec	15 sec	20 sec	20 sec

3.10.5 Precision Load Placement

a. Objectives.

- Check the ability to translate with, stabilize, and set down an external load at a specific location, within a reasonable time limit.
- Check ability to set load down without any residual motion of the load on the ground, such as dragging or swinging.

b. Description of maneuver. Initiate the maneuver at a ground speed between 6 and 10 knots, with a load clearance of 20 feet above ground level. The load placement target shall be oriented approximately 45 degrees relative to the heading of the rotorcraft. The load placement target is a ground referenced point, from which the deviation in the set-down point is measured. The ground track should be such that the rotorcraft will arrive over the target point (See Figure 31). Once the aircraft is stabilized in a hover over the load placement target, the crew chief will provide verbal instructions to assist the pilot in placing the load. These instructions should follow the form of *direction-count-hold* as in "Right, 3-2-1, hold" or "Down, 3-2-1, hold" to position the load and set it down.

c. Description of test course. The suggested test course for this maneuver is shown in Figure 31. Note that the desired and adequate boxes refer to the load set-down point, not the helicopter position during maneuver.

d. Performance standards. Accomplish the transition to hover in one smooth maneuver. It is not acceptable to accomplish most of the deceleration well before the load target point and then creep up to the final position. <u>The load swing should be contained within the desired boundaries (or adequate if trying for adequate performance) before placing the load on the ground.</u> The load should not perceptibly drift, swing, or drag after initial ground contact. All other performance standards are given below.

Performance – Precision Load Placement

	Externally Slung Load	
	GVE	DVE
DESIRED PERFORMANCE		N/A
• Attain a controlled hover within X seconds of initiation of deceleration:	10 sec	
• Maintain altitude during translation and hover within ±X ft:	4 ft	
• Controlled set-down of external load within X seconds of hover:	50 sec	
• Load set-down position should be within a box ±X ft larger than the footprint of the external load on all sides:	3 ft	
• The load should have no perceptible drift at touchdown	✓	
ADEQUATE PERFORMANCE		N/A
• Attain a controlled hover within X seconds of initiation of deceleration:	15 ft	
• Maintain altitude during translation and hover within ±X ft:	6 ft	
• Controlled set-down of external load within X seconds of hover:	120 sec	
• Load set-down position should be within a box ±X ft larger than the footprint of the external load on all sides:	6 ft	

3.10.6 Pirouette

a. Objectives.

- Check ability to accomplish precision control of the rotorcraft simultaneously in the pitch, roll, yaw, and heave axes.
- In the GVE, check ability to control the rotorcraft precisely in a moderate wind that is continuously varying in direction relative to the rotorcraft heading.
- In the DVE, check for degraded display symbology/dynamics during multiple axis maneuvering.

b. Description of maneuver. Initiate the maneuver from a stabilized hover over a point on the circumference of a 100 ft radius circle with the nose of the rotorcraft pointed at a reference point at the center of the circle, and at a hover altitude of approximately 15 ft. Accomplish a lateral translation around the circle, keeping the nose of the rotorcraft pointed at the center of the circle, and the circumference of the circle under a selected point on the rotorcraft. Maintain essentially constant lateral groundspeed throughout the lateral translation (note: nominal lateral velocity will be approximately 8 knots for the 45-sec and 6 knots for the 60-sec time around the circle). Terminate the maneuver with a stabilized hover over the starting point. Perform the maneuver in both directions. For a cockpit with side-by-side seating, the evaluation pilot should be allowed to sit in either seat to assess potential detrimental cueing effects on the handling qualities rating. In the GVE, the maneuver shall be accomplished in calm winds and in light winds from the most critical direction at the starting point.

c. Description of test course. The test course shall consist of markings on the ground that clearly denote the circular pathways that define desired and adequate performance and markings that denote a radial start/stop line. The suggested course shown in Figure 30 is considered adequate for the evaluation. It may also be useful to add objects to assist the pilot with vertical cueing, such as a post at the center of the circle. The desired hover reference point is bounded by the desired limits on the circle circumference and ±10 ft laterally from the radial start/stop line. The adequate hover reference point is bounded by the adequate limits on the circle circumference and ±15 ft laterally.

d. Performance standards.

Performance – Pirouette

	GVE	DVE
DESIRED PERFORMANCE		
• Maintain a selected reference point on the rotorcraft within ±X ft of the circumference of the circle.	10 ft	10 ft
• Maintain altitude within ±X ft:	3 ft	4 ft
• Maintain heading so that the nose of the rotorcraft points at the center of the circle within ±X deg:	10 deg	10 deg
• Complete the circle and arrive back over the starting point within:	45 sec	60 sec
• Achieve a stabilized hover (within desired hover reference point) within X seconds after returning to the starting point.	5 sec	10 sec
• Maintain the stabilized hover for X sec	5 sec	5 sec
ADEQUATE PERFORMANCE		
• Maintain a selected reference point on the rotorcraft within ±X ft of the circumference of the circle.	15 ft	15 ft
• Maintain altitude within ±X ft:	10 ft	10 ft
• Maintain heading so that the nose of the rotorcraft points at the center of the circle within ±X deg:	15 deg	15 deg
• Complete the circle and arrive back over the starting point within:	60 sec	75 sec
• Achieve a stabilized hover (within adequate hover reference point) within X seconds after returning to the starting point.	10 sec	20 sec
• Maintain the stabilized hover for X sec	5 sec	5 sec

3.10.7 Vertical Maneuver

a. Objectives.

For a scout/attack rotorcraft this maneuver is to simulate a rapid unmask/remask maneuver, with an aiming task at the unmask. For a utility or cargo rotorcraft, the maneuver is to assess the heave axis controllability with precision station keeping.

- Check for adequate heave damping, i.e., the ability to precisely start and stop a vertical rate.
- Check for adequate vertical control power.
- Check for undesirable coupling between collective and the pitch, roll, and yaw axes.
- Check the characteristics of the heave axis controller, especially if a non-conventional controller is used, e.g., a four-axis sidestick.
- With an external load, check for undesirable effects between the heave controller and the other axes of the rotorcraft and complications caused by the external load dynamics.

b. Description of maneuver. From a stabilized hover at an altitude of 15 ft, initiate a vertical ascent of 25 ft, stabilize for 2 seconds, and then descend back to the initial hover position. With an external load, the maneuver is initiated from a higher altitude to assure a 10 ft load clearance. In the GVE, the maneuver shall be accomplished in calm winds and in light winds from the most critical direction. If a critical direction has not been defined, the hover shall be accomplished with the wind blowing directly from the rear of the rotorcraft.

c. Description of test course. The test course shall consist of markings on the ground that clearly define desired and adequate performance. It is suggested that this maneuver use the hover course (Figure 29) with a second reference symbol or hover board set to align at the upper reference.

d. Performance standards.

Performance – Vertical Maneuver

	Scout/Attack		**Cargo/Utility**		**Externally Slung Load**	
	GVE	DVE	GVE	DVE	GVE	DVE
DESIRED PERFORMANCE						
• Maintain the longitudinal and lateral position within ±X ft of a point on the ground	6 ft	10 ft	3 ft	3 ft	3 ft	3 ft
• Maintain start/finish altitude within ±X ft:	3 ft	3 ft	3 ft	3 ft	4 ft	4 ft
• Maintain heading within ±X ft:	3 deg	3 deg	5 deg	5 deg	5 deg	5 deg
• Complete the maneuver within:	10 sec	13 sec	13 sec	15 sec	13 sec	15 sec
ADEQUATE PERFORMANCE						
• Maintain the longitudinal and lateral position within ±X ft of a point on the ground	10 ft	20 ft	6 ft	6 ft	6 ft	6 ft
• Maintain start/finish altitude within ±X ft:	6 ft	6 ft	6 ft	6 ft	6 ft	6 ft
• Maintain heading within ±X deg:	6 deg	6 deg	10 deg	10 deg	10 deg	10 deg
• Complete the maneuver within:	15 sec	18 sec	18 sec	18 sec	20 sec	20 sec

3.10.8 Depart/Abort

a. Objectives.

- Check pitch axis and heave axis handling qualities during moderately aggressive maneuvering.
- Check for undesirable coupling between the longitudinal and lateral-directional axes.
- Check for harmony between the pitch axis and heave axis controllers
- Check for overly complex power management requirements.
- Check for ability to re-establish hover after changing trim
- With an external load, check for dynamic problems resulting from the external load configuration.

b. Description of maneuver. From a stabilized hover at 35 ft wheel height (or no greater than 35 ft external load height) and 800 ft from the intended endpoint, initiate a longitudinal acceleration to perform a normal departure. Abort the departure and decelerate to a hover such that at the termination of the maneuver, the cockpit shall be within 20 ft of the intended endpoint. It is not permissible to overshoot the intended endpoint and move back. If the rotorcraft stopped short, the maneuver is not complete until it is within 20 ft of the intended endpoint. The acceleration and deceleration phases shall be accomplished in a single smooth maneuver. For rotorcraft that use changes in pitch attitude for airspeed control, a target of approximately 20 degrees of pitch attitude should be used for the acceleration and deceleration. The maneuver is complete when control motions have subsided to those necessary to maintain a stable hover.

c. Description of test course. The test course shall consist of at least a reference line on the ground indicating the desired track during the acceleration and deceleration, and markers to denote the starting and endpoint of the maneuver. The course should also include reference lines or markers parallel to the course reference line to allow the pilot and observers to perceive the desired and adequate longitudinal tracking performance, such as the example shown in Figure 33.

d. Performance standards.

Performance – Depart/Abort

	Cargo/Utility		**Externally Slung Load**	
	GVE	DVE	GVE	DVE
DESIRED PERFORMANCE				
• Maintain lateral track within ±X ft:	10 ft	10 ft	10 ft	10 ft
• Maintain radar altitude below X ft:	75 ft	75 ft	75 ft*	75 ft*
• Maintain heading within ±X deg:	10 deg	10 deg	10 deg	10 deg
• Time to complete maneuver:	25 sec	25 sec	30 sec	30 sec
• Maintain rotor speed within:	OFE	OFE	OFE	OFE
ADEQUATE PERFORMANCE				
• Maintain lateral track within ±X ft:	20 ft	20 ft	20 ft	20 ft
• Maintain radar altitude below X ft:	100 ft	100 ft	100 ft*	100 ft*
• Maintain heading within ±X deg:	15 deg	15 deg	15 deg	15 deg
• Time to complete maneuver:	30 sec	30 sec	35 sec	35 sec
• Maintain rotor speed within:	SFE	SFE	SFE	SFE

* Altitudes refer to height of external load, measured at hover

3.10.9 Lateral Reposition

a. Objectives.

- Check roll axis and heave axis handling qualities during moderately aggressive maneuvering.
- Check for undesirable coupling between the roll controller and the other axes.
- With an external load, check for dynamic problem resulting from the external load configuration.

b. Description of maneuver. Start in a stabilized hover at 35 ft wheel height (or no greater than 35 ft external load height) with the longitudinal axis of the rotorcraft oriented 90 degrees to a reference line marked on the ground. Initiate a lateral acceleration followed by a deceleration to laterally reposition the rotorcraft in a stabilized hover 400 ft down the course within a specified time. The acceleration and deceleration phases shall be accomplished as single smooth maneuvers. The rotorcraft must be brought to within ±10 ft of the endpoint during the deceleration, terminating in a stable hover within this band. Overshooting is permitted during the deceleration, but will show up as a time penalty when the pilot moves back within ±10 ft of the endpoint. The maneuver is complete when a stabilized hover is achieved. Perform the maneuver both to the right and to the left. For a cockpit with side-by-side seating, the evaluation pilot should be allowed to sit in either seat to assess potential detrimental cueing effects on the handling qualities rating.

c. Description of test course. The test course shall consist of any reference lines or markers on the ground indicating the desired track and tolerances for the acceleration and deceleration, and markers to denote the starting and endpoint of the maneuver. The course should also include reference lines or markers parallel to the course reference line to allow the pilot and observers to perceive the desired and adequate longitudinal tracking performance, such as the example shown in Figure 32.

d. Performance standards.

Performance – Lateral Reposition

	Cargo/Utility		**Externally Slung Load**	
	GVE	DVE	GVE	DVE
DESIRED PERFORMANCE				
• Maintain longitudinal track within ±X ft:	10 ft	10 ft	10 ft	10 ft
• Maintain altitude within ±X ft:	10 ft	10 ft	10 ft	10 ft
• Maintain heading within ±X deg:	10 deg	10 deg	10 deg	10 deg
• Time to complete maneuver:	18 sec	20 sec	25 sec	25 sec
ADEQUATE PERFORMANCE				
• Maintain longitudinal track within ±X ft:	20 ft	20 ft	20 ft	20 ft
• Maintain altitude within ±X ft:	15 ft	15 ft	15 ft	15 ft
• Maintain heading within ±X deg:	15 deg	15 deg	15 deg	15 deg
• Time to complete maneuver:	22 sec	25 sec	30 sec	30 sec

3.10.10 Slalom

a. Objectives.

- Check ability to maneuver aggressively in forward flight and with respect to objects on the ground.
- Check turn coordination for moderately aggressive forward flight maneuvering.
- Check for objectionable interaxis coupling during moderately aggressive forward flight maneuvering.
- In the DVE, check ability to maneuver moderately aggressive with respect to objects on the ground.

b. Description of maneuver. Initiate the maneuver in level unaccelerated flight and lined up with the centerline of the test course. Perform a series of smooth turns at 500-ft intervals* (at least twice to each side of the course). The turns shall be at least 50 ft from the centerline, with a maximum lateral error of 50 ft. The maneuver is to be accomplished below the reference altitude. Complete the maneuver on the centerline, in coordinated straight flight.

c. Description of test course. The suggested test course for this maneuver is shown in Figure 34. Most runways have touchdown stripes at 500-ft intervals that can be conveniently used instead of the pylons. However, if the runway is not 100 ft wide, it will be necessary to use two cones to define each gate (as opposed to one cone and the runway edge as shown in Figure 34).

d. Performance standards.

Performance – Slalom

	GVE	DVE
DESIRED PERFORMANCE		
• Maintain an airspeed of at least X knots throughout the course	60	30
• Accomplish maneuver below reference altitude of X ft:	Lesser of twice rotor diameter# or 100 ft	100 ft
ADEQUATE PERFORMANCE		
• Maintain an airspeed of at least X knots throughout the course	40	15
• Accomplish maneuver below reference altitude of X ft:	100 ft	100 ft

* Note: The 500-ft interval spacing has successfully been used for several flight tests (e.g., AH-64, Bo 105, CH-47, and UH-60). However, for larger aircraft (e.g, CH-53), experience has shown that the Slalom 500-ft interval gate spacing was too tight and it was expanded by 25-meters to 580-ft spacing. Requests for these changes shall be defined and submitted to the Government for approval prior to testing.

Note: For rotorcraft with side-by-side rotors (e.g., tiltrotor), the tip-to-tip distance shall be used for "rotor diameter" parameter.

3.10.11 Vertical Remask

a. Objectives.

- Check ability to accomplish an aggressive vertical descent close to the ground.
- Check ability to combine vertical and lateral aggressive maneuvering as required to evade enemy fire if observed during a bob-up.

b. Description of maneuver. From a stabilized hover at 75 ft, remask vertically to an altitude below 25 ft. Then rapidly displace the rotorcraft laterally 300 ft and stabilize at a new hover position. During the vertical remask simulate deploying rotorcraft survivability equipment as appropriate. Accomplish the maneuver to the left and to the right.

c. Description of test course. The test course should include markers to denote the desired and adequate performance related to position during the vertical descent and final stabilized hover. It may also be desirable to include a vertical reference to provide cues related to the 25 ft altitude reference. This maneuver assumes that the pilot is remasking behind some object, and such an altitude reference should therefore be available. A suggested test course for this maneuver is shown in Figure 32.

d. Performance standards.

Performance – Vertical Remask

	DESIRED	ADEQUATE
• Achieve an altitude of X or less within 6 seconds of initiating the maneuver.	25 ft	N/A
• During initial stabilized hover, vertical descent, and final stabilized hover, maintain longitudinal and lateral position within ±X ft of a reference point on the ground.	8 ft	12 ft
• Maintain altitude after remask and during displacement within X ft:	±10 ft	+10 and -15 ft
• Maintain lateral ground track within ±X ft:	10 ft	15 ft
• Maintain heading within ±X deg	10 deg	15 deg
• Achieve a stabilized hover within X sec after reaching the final hover position.	5 sec	10 sec
• Achieve the final stabilized hover within X sec of initiating the maneuver.	15 sec	25 sec

3.10.12 Acceleration and Deceleration

a. Objectives.

- Check pitch axis and heave axis handling qualities:
  - (GVE): for aggressive maneuvering near the rotorcraft limits of performance.
  - (DVE): for reasonably aggressive maneuvering in the DVE.
- Check for undesirable coupling between the longitudinal and lateral-directional axes.
- Check for harmony between the heave axis and pitch axis controllers.
- Check for adequate rotor response to aggressive collective inputs.
- Check for overly complex power management requirements.

b. Description of maneuver. Start from a stabilized hover. In the GVE, rapidly increase power to approximately maximum, maintain altitude constant with pitch attitude, and hold collective constant during the acceleration to an airspeed of 50 knots. Upon reaching the target airspeed, initiate a deceleration by aggressively reducing the power and holding altitude constant with pitch attitude. The peak nose-up attitude should occur just before reaching the final stabilized hover. In the DVE, accelerate to a groundspeed of at least 50 knots, and immediately decelerate to hover over a defined point. The maximum nose-down attitude should occur immediately after initiating the maneuver, and the peak nose-up attitude should occur just before reaching the final stabilized hover. Complete the maneuver in a stabilized hover for 5 seconds over the reference point at the end of the course.

c. Description of test course. The test course shall consist of a reference line on the ground indicating the desired track during the acceleration and deceleration, and markers to denote the starting point and endpoint of the maneuver. The distance from the starting point to the final stabilized hover position is a function of the performance of the rotorcraft, and shall be determined based on trial runs consisting of acceleration to the target airspeed, and decelerations to hover as described above. The course should also include reference lines or markers parallel to the course centerline to allow the pilot and observers to perceive desired and adequate lateral tracking performance. A suggested test course is shown in Figure 33.

d. Performance standards.

Performance – Acceleration and Deceleration

	GVE	DVE
DESIRED PERFORMANCE		
• Within X seconds from initiation of the maneuver, achieve at least the greater of 95% maximum continuous power or 95% maximum transient limit that can be sustained for the required acceleration, whichever is greater. If the 95% power results in objectionable pitch attitudes, use the power corresponding to the maximum nose-down pitch attitude that is felt to be acceptable. This pitch attitude shall be considered as a limit of the Operational Flight Envelope (OFE) for NOE flying.	1.5 sec	N/A
• Achieve a nose-down pitch attitude during the acceleration of at least X deg below the hover attitude:	N/A	12 deg
• Maintain altitude below X ft:	50 ft	50 ft
• Maintain lateral track within ±X ft:	10 ft	10 ft
• Maintain heading within ±X deg:	10 deg	10 deg
• Decrease power to less than 5% within X seconds to initiate deceleration.	3 sec	N/A
• Significant increases in power are not allowed until just before the final stabilized hover.	✓	✓
• Achieve a nose-up pitch attitude during the deceleration of at least X deg above the hover attitude. The maximum pitch attitude should occur shortly before the hover.	30 deg	15 deg
• Longitudinal tolerance on the final hover point is plus zero, minus a distance equal to X % of the overall rotorcraft length.	50 %	50 %
• Rotor RPM shall remain within the limits of X without undue pilot compensation	OFE	OFE
ADEQUATE PERFORMANCE		
• Within X seconds from initiation of the maneuver, achieve at least the greater of 95% maximum continuous power or 95% maximum transient limit that can be sustained for the required acceleration, whichever is greater. If the 95% power results in objectionable pitch attitudes, use the maximum nose-down pitch attitude that is felt to be acceptable. This pitch attitude shall be considered as a limit of the Operational Flight Envelope (OFE) for NOE flying.	3 sec	N/A
• Achieve a nose-down pitch attitude during the acceleration of at least X deg below the hover attitude.	N/A	7 deg
• Maintain altitude below X ft:	70 ft	70 ft
• Maintain lateral track within ±X ft:	20 ft	20 ft
• Maintain heading within ±X ft:	20 deg	20 deg
• Decrease power to less than 30% of maximum within X seconds to initiate deceleration.	5 sec	N/A
• Significant increases in power are not allowed until just before the final stabilized hover.	✓	✓
• Achieve a nose-up pitch attitude during the deceleration of at least X deg above the hover attitude.	10 deg	10 deg
• Longitudinal tolerance on the final hover point is minus a distance equal to X % of the overall rotorcraft length.	100 %	100 %
• Rotor RPM shall remain within the limits of the:	SFE	SFE

3.10.13 Sidestep

a. Objectives.

- Check lateral-directional handling qualities for aggressive maneuvering near the rotorcraft limits of performance (GVE), or reasonably aggressive lateral maneuvering (DVE).
- Check for objectionable interaxis coupling.
- Check ability to coordinate bank angle and collective to hold constant altitude.

b. Description of maneuver. Starting from a stabilized hover with the longitudinal axis of the rotorcraft oriented 90 degrees to a reference line marked on the ground, initiate a rapid and aggressive lateral acceleration, holding altitude constant with power. Hold target velocity for 5 seconds and then initiate an aggressive deceleration to hover at constant altitude. The peak bank angle during deceleration should occur just before the rotorcraft comes to a stop. Establish and maintain a stabilized hover for 5 seconds. Immediately repeat the maneuver in the opposite direction. For a cockpit with side-by-side seating, the evaluation pilot should be allowed to sit in either seat to assess potential detrimental cueing effects on the handling qualities rating.

c. Description of test course. The test course shall consist of any reference lines or markers on the ground indicating the desired track and tolerances for the acceleration and deceleration, and markers to denote the starting and endpoint of the maneuver. The course should also include reference lines or markers parallel to the course reference line to allow the pilot and observers to perceive the desired and adequate longitudinal tracking performance, such as the example shown in Figure 32. Note that the end point for this maneuver is not prescribed.

d. Performance standards.

Performance – Sidestep

	GVE	DVE
DESIRED PERFORMANCE		
• Achieve at least 25 degrees of bank angle change from trim, or target airspeed, within X seconds of initiating the maneuver:	1.5 sec	N/A
• Achieve a target airspeed of X knots:	lesser of 40 or (OFE-5) knots	17 knots
• Achieve at least 30 degrees of bank angle within X seconds of initiating deceleration:	1.5 sec	N/A
• Achieve at least X deg of bank angle change from trim during the acceleration and deceleration:	N/A	20 deg
• Maintain a selected reference point on the rotorcraft within ±X ft of the ground reference line:	10 ft	10 ft
• Maintain altitude within ±X ft at a selected altitude below 30 ft:	10 ft	10 ft
• Maintain heading within ±X deg:	10 deg	10 deg
• Achieve a stabilized hover within X seconds after reaching the hover point:	5 sec	10 sec
ADEQUATE PERFORMANCE		
• Achieve at least 25 degrees of bank angle change from trim, or target airspeed, within X seconds of initiating the maneuver:	3.0 sec	N/A
• Achieve a target airspeed of X knots:	lesser of 40 or (OFE-5) knots	17 knots
• Achieve at least 30 degrees of bank angle within X seconds of initiating deceleration:	3.0 sec	N/A
• Achieve at least X deg of bank angle during the acceleration and deceleration:	N/A	10 deg
• Maintain a selected reference point on the rotorcraft within ±X ft of the ground reference line:	15 ft	15 ft
• Maintain altitude within ±X ft at a selected altitude below 30 ft:	15 ft	15 ft
• Maintain heading within ±X deg:	15 deg	15 deg
• Achieve a stabilized hover within X seconds after reaching the hover point:	10 sec	20 sec

3.10.14 Deceleration to Dash

a. Objectives.

- Check for poor engine governing or overly complex power management requirement.
- Check pitch, heave, and yaw axis handling qualities for aggressive maneuvering.
- Check for undesirable coupling between the longitudinal and lateral-directional axes, and between the heave axis and longitudinal and lateral-directional axes, for maneuvers requiring large power changes.
- Check for harmony between the heave, pitch, and directional axis controllers.
- Check for adequate rotor response to aggressive collective inputs.

b. Description of maneuver. From level unaccelerated flight at the lesser of V_H or120 knots, perform a level deceleration-acceleration. Adjust the pitch attitude to maintain altitude with a full down collective position. As the airspeed decreases to approximately 50 knots, aggressively assume the attitude for maximum acceleration and rapidly increase power to approximately the maximum, and maintain that power until the initial airspeed is reached.

c. Description of test course. Any reference line on the ground will serve as an adequate test course for this maneuver.

d. Performance Standards. The entire maneuver shall be conducted below 200 ft.

Performance – Deceleration to Dash

	DESIRED	ADEQUATE
• Achieve X% collective within Y sec from the initiation of the deceleration.	0% (full down) 3 sec	Less than 10% 5 sec
• Achieve either X% of maximum continuous power (or X% of the transient limit) within Y sec of initiating the acceleration.	95% 2 sec	80% 3 sec
• During the acceleration, the power shall not exceed any rotorcraft limitation, and shall not fall below X%.	85%	80%
• Without undue pilot compensation, rotor RPM shall remain within the limits of the:	OFE	SFE
• Maintain heading within ±X deg:	5 deg	10 deg
• Maintain altitude below X ft:	200 ft	200 ft
• Maintain altitude within ±X ft:	50 ft	N/A
• Any oscillations or coupling shall not be:	undesirable	objectionable

3.10.15 Transient Turn

a. Objectives.

- Insure that handling qualities do not degrade during aggressive maneuvering in all axes.
- Check for undesirable coupling between pitch, roll, and yaw during aggressive maneuvering.

b. Description of maneuver. Starting at the lesser of V_H or 120 knots and an altitude at or below 200 ft, accomplish a 180-degree change in directional flightpath and achieve wings-level attitude in as little time as possible. Use of pedals to induce a lateral acceleration in the direction of the turn is acceptable. Perform the maneuver both to the right and to the left. It is acceptable to reduce collective to increase the rate of speed bleed-off and thereby maximize the turn rate.

c. Description of test course. This maneuver does not require a test course that is marked out on the ground aside from a reference line such as a road or railroad track.

d. Performance standards.

Performance – Transient Turn

	DESIRED	ADEQUATE
• Achieve a peak normal load factor of at least X% of the OFE $n_L(+)$:	100%-0.2g	80%
• Complete the maneuver within X seconds:	10 sec	15 sec
• Maintain altitude within X ft:	±50 ft	Below 300 ft
• Maintain the rotor RPM within the limit of the:	OFE	SFE
• Wings-level attitude on roll out within X degrees of level trim:	5 deg	10 deg

3.10.16 Pullup/Pushover

a. Objectives.

- Check handling qualities at elevated and reduced load factors and during transition between elevated and reduced load factors.
- Check for undesirable coupling between pitch, roll, and yaw for aggressive maneuvering in forward flight.
- Check for ability to avoid obstacles during high-speed NOE operations.

b. Description of maneuver. From level unaccelerated flight at the lesser of V_H or 120 knots, attain a sustained positive load factor in a symmetrical pullup. Transition, via a symmetrical pushover, to a sustained negative load factor. Recover to level flight as rapidly as possible.

c. Description of test course. This maneuver may be accomplished up-and-away, and no test course is required.

d. Performance standards.

Performance – Pullup/Pushover

	DESIRED	ADEQUATE
• Attain a normal load factor of at least the positive limit of the OFE ($n_L(+)$) within X seconds from the initial control input.	1 sec	2 sec
• Maintain at least $n_L(+)$ for at least X seconds	2 sec	1 sec
• Accomplish transition from $n_L(+)$ pullup to a pushover of not greater than the negative normal load factor limit of the OFE ($n_L(-)$) within X seconds.	2 sec	4 sec
• Maintain a load factor of not greater than $n_L(-)$ for at least X seconds.	2 sec	1 sec
• Maintain angular deviations in roll and yaw within ±X degrees from the initial unaccelerated level flight condition to completion of the maneuver.	10 deg	15 deg

3.10.17 Roll Reversal

a. Objectives.

- Check handling qualities while maneuvering with load factors close to the OFE limits.
- Check the roll damping and roll authority during elevated and reduced load factor.
- Check for undesirable coupling between axes during aggressive maneuvering.
- Check the maneuvering stability of the rotorcraft close to the OFE limits.

b. Description of maneuver. Starting in a dive, conduct a series of pullups and pushovers to achieve normal accelerations within 0.10g of the positive [n_L(+)] and negative [n_L(-)] boundaries of the Operational Flight Envelope. The target normal acceleration should occur as the rotorcraft passes through the level attitude. At this time execute an aggressive roll to a minimum of 45 degrees of bank, and back to zero while maintaining incremental load factor. The maneuvers should be conducted so that the airspeed at the start of the rolling maneuvers is the lesser of V_H or 120 knots.

c. Description of test course. This maneuver may be accomplished up-and-away, and no test course is required.

d. Performance standards.

Performance – Roll Reversal

	DESIRED	ADEQUATE
• Achieve a peak roll rate of at least X percent of the maximum steady state roll rate achievable at one g:	50%	30%
• Maintain target normal acceleration within X % of the incremental load factor:	50%	50%
• No oscillation in any axis that is:	Undesirable	Uncontrollable or persistent
• Any change in roll or pitch response shall not be:	Sudden	Objectionable or reversals

3.10.18 Turn to Target

a. Objectives.

- Check for undesirable handling qualities during a maximum effort, rapid hovering turn.
- Check ability to recover from a rapid hovering turn with sufficient precision to fire a weapon.
- Check for undesirable interaxis coupling.

b. Description of maneuver. From a stabilized hover at an altitude of less than 20 ft, complete a 180 degree turn. Turns shall be completed in both directions. The final heading tolerance should be based on a sight mounted on the rotorcraft, preferably the same sight to be used for operational missions.

c. Description of test course. The test course can consist of any convenient target.

d. Performance standards.

Performance – Turn to Target

	DESIRED	ADEQUATE
• Maintain longitudinal and lateral position of a selected point on the rotorcraft within ±X ft of a reference point on the ground.	6 ft	12 ft
• Maintain altitude within ±X ft	3 ft	6 ft
• Stabilize final rotorcraft heading within a tolerance based on the firing constraints of the weapon system to be deployed on the rotorcraft.	✓	N/A
• Stabilize final rotorcraft heading within ±X deg:	N/A	3 deg
• Complete the turn so that a firing solution has been achieved within X from initiation of the maneuver.	5 sec	10 sec

3.10.19 High Yo-Yo

a. Objectives.

- Check handling qualities during reduced and elevated load factors.
- Check the short term-response characteristics of the rotorcraft through aggressive pitch pointing tasks.
- Check for undesirable coupling between pitch, roll, and yaw during aggressive maneuvering.

b. Description of maneuver. Two aircraft are required to perform this air-combat maneuver. The maneuver is initiated from level unaccelerated flight with both aircraft at a constant airspeed equal to the V_H of the test rotorcraft. The test rotorcraft is positioned at least 500 ft in trail behind the target aircraft. The target aircraft then decelerates 20 knots, to (V_H - 20), causing the test rotorcraft to close on the target. When the range between the two aircraft decreases to approximately 300 ft, the target aircraft initiates a 45-degree banked turn at constant altitude, and holds the turn to roll out after 180 deg heading change. The test rotorcraft delays until the line-of-sight reaches 30 degrees, at which time the pilot initiates a climbing turn toward the target, with a nose-up pitch attitude of 15 to 30 degrees. The resulting deceleration causes a decrease in the rate of closure from above. When the closure rate is no longer apparent, and the range to the target is approximately 200 to 500 ft, the test rotorcraft rapidly lowers the nose to achieve a firing solution within missile launch constraints.

c. Description of test course. This maneuver may be accomplished up-and-away, and no test course is required.

d. Performance standards.

Performance – High Yo-Yo

	DESIRED	ADEQUATE
• Interaxis coupling shall not be:	Undesirable	Objectionable
• Maintain the missile launch constraints for X sec:	7 sec	4 sec
• Acquire the target with no tendency for pitch overshoots	✓	✓

3.10.20 Low Yo-Yo

a. Objectives.

- Check handling qualities during reduced and elevated load factors.
- Check the short-term response characteristics of the rotorcraft through aggressive pitch pointing tasks.
- Check for undesirable coupling between pitch, roll, and yaw during aggressive maneuvering.

b. Description of maneuver. Two aircraft are required to perform this air-combat maneuver, and the target aircraft must be capable of achieving airspeeds of at least V_H of the test rotorcraft. The maneuver is initiated from level unaccelerated flight, with both aircraft at an airspeed equal to (V_H - 20 knots) of the test rotorcraft. The test rotorcraft is positioned approximately 200 ft in trail behind the target aircraft. The target aircraft then accelerates 20 knots to V_H, resulting in a steady increase in range between the two aircraft. When the range between the two aircraft increases to approximately 300 ft, the target aircraft executes a 45-degree banked turn at constant altitude and holds the turn to roll out after 180 deg heading change. The test rotorcraft delays until the line-of-sight reaches 30 degrees, at which time the pilot initiates a diving turn in the direction of the target with a nose-down pitch attitude of 15 to 30 degrees. The resulting acceleration causes the test rotorcraft to begin to close on the target from below. When a rate of closure on the target is apparent, and the range to the target is within 500 ft, the test rotorcraft rapidly raises the nose and tracks the target to achieve a firing solution within missile launch constraints.

c. Description of test course. This maneuver may be accomplished up and away, and no test course is required.

d. Performance standards.

Performance – Low Yo-Yo

	DESIRED	ADEQUATE
• Interaxis coupling shall not be:	Undesirable	Objectionable
• Maintain the missile launch constraints for X sec:	7 sec	4 sec
• Acquire the target with no tendency for pitch overshoots	✓	✓
• Maintain power within the transient range for as long as possible, without exceeding the time limit specified for the rotorcraft, or until simulated missile launch. Maintain at least 95% of maximum continuous power when rotorcraft limitations prohibit operation in the transient range.	✓	N/A
• Maintain power within ±10% of maximum continuous. If +10% exceeds a limit, do not exceed that limit.	N/A	✓

3.10.21 Decelerating Approach

a. Objectives.

- Check ability to perform precision glideslope and localizer tracking to very low decision height and groundspeed with a reasonable pilot workload.
- Check ability to precisely control airspeed and to perform a deceleration while descending on the glideslope.

b. Description of maneuver. Start the maneuver in level flight on the localizer outside the final approach fix (FAF) at V_H. Once established on glideslope and localizer decelerate to 60 KIAS or V_{mini}, whichever is less, in one minute or less. Terminate the maneuver when stabilized on the localizer and glideslope at 60 KIAS (or V_{mini}).

c. Performance standards.

Performance – Decelerating Approach

	DESIRED	ADEQUATE
• Final target airspeed 60 kts or V_{mini}, whichever is less:	±5 kts	±10 kts.
• Maintain glideslope and localizer within:	1 dot	2 dots
• Prior to glideslope intercept, maintain altitude within:	±100 ft	±200 ft.

3.10.22 ILS or LPV Approach

a. Objectives.

- Check ability to perform precise flight path and speed control.

b. Description of maneuver. Start level on localizer and 100 kts airspeed outside the final approach fix (FAF)[1]. After established on the localizer and glideslope, and inside the FAF, turn to a heading of 30 degrees off the localizer course and establish zero vertical speed to achieve two dots left or right and two dots high. In most cases, the localizer will reach two dots before the glideslope reaches two dots. In that case, turn to parallel the final approach course until the glideslope deviation reaches two dots. Initiate a correction back to the glideslope and localizer and start a timer. Achieve a stable tracking solution on localizer and glideslope with 1/4 dot and stop the timer[2]. (If the glideslope reaches two dots before the localizer reaches two dots, establish a 500 ft/min rate of descent (3 deg flight path angle) until the localizer reaches two dots).

If the glideslope angle is greater than 4 degrees, it is acceptable to reduce the glideslope deviation to a value that does not result in entering autorotation as long as that deviation does not exceed one dot.

c. Performance standards.

Performance – ILS or LPV Approach

	DESIRED	ADEQUATE
• Maintain target airspeed:	±10 kts	±15 kts.
• Prior to glideslope intercept, Maintain altitude within:	±50 ft.	±100 ft.
• Maintain glideslope and localizer within:	1/2 dot	1 dot
• Accomplish capture maneuver within:	1 minute	1.5 min.

Airspeed excursions may exceed noted values by 5 kts in moderate turbulence.

[1] The terms localizer and glideslope are intended to be applicable to RNAV glidepath and approach course.

[2] It is intended that the capture be accomplished within ¼ dot prior to stopping the time. Subsequent tracking should be within the limits specified in the table.

3.10.23 Missed Approach

a. Objectives.

- Check longitudinal flight control variations in a high-workload, divided-attention task.

b. Description of maneuver. Following an ILS approach to Decision Height, (200 ft a.g.l), initiate a climb on runway heading to 500 feet a.g.l. by increasing power to maximum torque and pitch to maintain V_Y. If that results in a rate of climb greater than 2,000 ft/min, use an airspeed that results in approximately 2,000 ft/min. rate of climb.

At 500 feet a.g.l, turn right (or left) to a heading of 90 degrees from runway heading. Level off at 1000 feet a.g.l. and accelerate to 100 kts. Once steady at 100 kts, 1,000 ft a.g.l, and on heading, initiate a climbing right (or left) turn to a heading of 180 deg from runway heading and climb to 2,000 ft a.g.l. as rapidly as possible. Level off at 2,000 ft a.g.l. while maintaining 100 kts. When established at 100 kts, 2,000 ft, a.g.l. and on heading, accelerate to V_H.

c. Performance standards.

Performance – Missed Approach

	DESIRED	ADEQUATE
• Maintain altitudes within:	±100 ft.	±200 ft.
• Maintain target airspeeds within:	±10 kts.	±15 kts.
• Maintain target heading within	±10 deg	±20 deg

3.10.24 Speed Control

a. Objectives.

- Investigate airspeed control to assess adequacy of stick force gradient with airspeed.

b. Description of maneuver. From trimmed level flight at 90 knots, decelerate to 70 knots and retrim for hands-off flight. Then accelerate to 90 knots and retrim for hands off flight. Finally, accelerate to 110 knots and retrim.

c. Performance standards.

Performance – Speed Control

	DESIRED	ADEQUATE
• Maintain altitude within ±X ft:	100 ft	200 ft
• Trim hands-off at target airspeed within ±X knots:	3 knots	5 knots
• Change from one trim airspeed to another within X minutes:	1 minute	2 minutes
• Maintain heading within ±X deg:	5 deg	10 deg

4. VERIFICATION

4.1 General

Compliance with the requirements of this specification shall be demonstrated using analysis, simulation, and flight test at appropriate milestones during the rotorcraft design and development. In absence of other guidance from the system specification, Table XV and Table XVI shall be observed. Table XV indicates the appropriate milestones for analysis, simulation and flight test. Table XVI indicates the range of Rotorcraft Status and Flight Conditions from which specific combinations shall be selected to demonstrate compliance with this specification. Complexity and scope of these demonstrations are defined in 4.1.1, 4.1.2, and 4.1.3.

4.1.1 Analysis

Initially the quantitative flying qualities criteria shall be assessed analytically (non-piloted) using available math models that represent the aerodynamic, flight control system, and engine/fuel control characteristics of the rotorcraft.

By PDR, and thereafter, analytical checks shall be accomplished using full nonlinear math models including best estimates of engine/fuel controls, rotor system, and SCAS elements. The Configurations, Loadings, and SCAS modes should be well defined. HQ shall be evaluated at selected conditions throughout the OFE, at least for Normal States. By CDR the Failure States shall be defined and included in the analyses. Analysis shall be continued throughout the development program to supplement the simulation and flight testing.

4.1.2 Simulation

Piloted simulation with representative cockpit controls and displays including the feel system shall be used by the CDR milestone. The simulator shall include a visual attachment, but does not require a motion system unless such a system is specified by the system specification. The simulation shall include a validated representation of all controls and displays that will be available to the pilot for control of the rotorcraft. Rotorcraft Status to be tested shall include all mission-required Configurations at nominal and critical Loadings. All Settings shall be available and evaluated. In addition, failure transients and steady state Failure States shall be investigated. Although the piloted simulation environment is primarily to investigate the MTEs, many of the quantitative tests are intended to include the pilot-rotorcraft interface and so a sample shall be repeated in the piloted simulator environment. Any discrepancies between the piloted simulator results and the off-line math model results shall be investigated and resolved.

It has been found that tests should be performed to determine the Simulated Day Usable Cue Environment of the simulator (SIMDUCE), using the test methodology specified in 3.2.1 for determination of the UCE. If the SIMDUCE is greater than one, it is likely that the pilot ratings (HQRs) will be in the Level 2 range (HQR between 4 and 6), even though the actual rotorcraft would be Level 1. The key indicator of acceptable Level 1 HQ is that the pilot comments clearly associate the Level 2 deficiencies with deficient visual cueing.

Simulated vision aids shall be calibrated to insure the visual acuity is consistent with the estimated performance of that vision aid in the DVE specified as part of the operating environment. It should be possible to achieve Level 1 pilot ratings in the simulated DVE, when employing the flight control modes designed for operations in DVE.

Validation of the simulator shall include comparisons of the response of the math model and the visual scene with responses obtained from the validated non-real-time simulation to identical cockpit controller inputs. The lag between the cockpit control input and the out-the-window visual scene response shall not cause a change from the rotorcraft’s true Bandwidth and Phase Delay that is equivalent to more than ½ a point in estimated HQR. The increment of HQR is obtained by interpolation on the appropriate Bandwidth criteria figure. If the out-the-window scene is generated by a remotely located sensor, the head tracking dynamic response and the image source location shall be represented.

4.1.3 Flight

For SVR verification, flight tests shall be performed to demonstrate both the quantitative and subjective requirements of this specification and to show that the predicted Levels of HQ and the assigned Levels of HQ are as required.

Based on the analysis and simulation results the contractor shall develop a test plan to adequately demonstrate the full-mission capability and define limiting conditions. The test plan shall be subject to approval by the Government.

All of the quantitative criteria shall be tested. The tests shall be performed for a sample of Configurations and Loadings, all Normal States and selected Failure States, at a range of Flight Conditions. The sample shall be sufficient to assess validity of the analysis and simulation results, and if adequate fidelity is demonstrated further testing may be limited in scope. Emphasis shall be on data points that are critical from the standpoint of handling qualities and safety, but shall also demonstrate performance at important nominal mission conditions.

Qualitative flight test evaluations shall be performed to provide an overall check of the HQ. All applicable MTEs shall be demonstrated in primary mission configuration, with primary or augmented SCAS mode in normal state(s) with Loadings that are most critical for HQ. Selected MTEs shall be performed to evaluate the HQ with secondary SCAS mode (or configurations corresponding to $Pf > 10^{-5}$). All ground-referenced MTEs shall be performed in calm winds. In addition, the Hover, Hovering Turn, Pirouette, and Vertical Maneuver shall be performed in the GVE in light winds. The Government will decide if the extent of HQR degradation due to light winds is acceptable.

All of the quantitative testing, and the flight tests of the GVE MTEs, shall be conducted in day good visual conditions (GVE). The DVE MTEs shall be tested in real DVE when evaluating the primary or augmented SCAS in normal state. The Secondary SCAS may be tested in simulated DVE.

It is not necessary to perform the MTE evaluations in a high density altitude environment unless the rotorcraft has been shown to not meet one or more of the quantitative boundaries, and satisfactory results in the MTE tests are being used to support a deviation.

4.2 Levels of handling qualities

Handling qualities depend on the aircraft's flying characteristics, the piloting task being performed, the Usable Cue Environment, wind and turbulence, and any additional demands on the pilot. Levels of handling qualities are defined by the 1 to 3, 4 to 6, and 7 to 8 ranges of the Cooper-Harper Handling Qualities Rating (HQR) Scale (Figure 1). This specification uses two distinct methods of establishing Levels of handling qualities, Predicted Levels and Assigned Levels. Predicted Levels are obtained from quantitative criteria that are based on HQR data from engineering in-flight and ground-based simulation. This knowledge is not complete; data are not available to fully define the required limit for all flying qualities parameters which taken together will ensure good handling qualities for all mission tasks. Assigned Levels are obtained from test pilots using the HQR Scale (Figure 1) to assess the workload and task performance required to perform designated MTEs. The MTE flight test maneuvers are not sufficiently comprehensive to represent all mission maneuvers in all environments that a particular rotorcraft may be called upon to perform, nor is it practical to perform the designated MTEs throughout the OFE for all loadings. Since neither the Predicted Levels nor the Assigned Levels provide a complete comprehensive assessment of handling qualities, compliance with both methods is necessary to maximize the likelihood of an accurate assessment of the Level of handling qualities. If there are conflicts between the Predicted Levels and Assigned Levels, the quantitative criteria and the MTE results shall be scrutinized to determine the cause of the discrepancy. On the basis of this investigation, the Government will determine whether or not compliance has been achieved or if further testing is required.

4.3 Testing with externally slung loads

Testing of applicable MTEs with externally slung loads shall be accomplished with a load mass ratio (6.2.8) of 0.30 or the maximum load that will be used for operational missions, whichever is less. If load mass ratios of greater than 0.30 will be used operationally, a configuration with the maximum load mass shall also be tested. The Government will decide if HQR degradations at high load mass ratios are acceptable. Testing shall be accomplished in both GVE and DVE if required by 3.1.1.

4.4 Interpretation of subjective requirements

In several instances throughout the specification, subjective terms such as essentially constant, objectionable delays, excessively sluggish, and complex coordination, have been employed where insufficient information exists to establish quantitative criteria. Such requirements shall be interpreted with due regard to the intent of the Level definitions of 3.1.5. Final determination of compliance with requirements so worded shall be determined through flight test or other suitable means subject to Government approval.

5. PACKAGING

For acquisition purposes, the packaging requirements shall be as specified in the contract or order.

6. NOTES

This section contains information of a general or explanatory nature which may be helpful but is not mandatory.

6.1 Intended use

This performance specification establishes requirements for the flying and ground handling qualities of military rotorcraft. It is intended that the specification should cover land-based rotorcraft that have primary missions ranging from scout and attack to utility and cargo. Additional requirements or modified standards may be required for rotorcraft that operate from small ships in sea states resulting in more than small ship motion.

The requirements are intended for application in development of a new system, or for a major system upgrade. If met, they should assure that no limitations on flight safety, or on the capability to perform intended missions, will result from deficiencies in flying qualities. The criteria and MTEs can also be used as a development tool since they provide quantitative benchmarks and calibrated maneuver standards which may be valuable for assessing the need for upgrades, or for diagnosing the cause of deficient performance.

Application of this specification to a specific system requires minimal tailoring. This tailoring basically consists of selecting the appropriate MTEs corresponding to the operational missions, and defining several aspects of the operational environment. All of the topics to be specified in the system specification have been gathered into 3.1. Guidance on tailoring these topics will be provided in a separate handbook.

6.2 Definitions

6.2.1 Acronyms

The acronyms used in this specification are defined as follows:

A	Analysis method for verification
ACAH	Attitude Command/Attitude Hold Response-Type
AH	Attitude Hold
CDR	Critical Design Review – Midterm project milestone
DH	Direction [Heading] Hold
DVE	Degraded Visual Environment to be defined by system specification, but typically night with some form of visual aid such as night vision goggles
FAF	Final Approach Fix
FFR	First Flight Readiness Review – Project milestone
F_s/n	Control force per g
GVE	Good Visual Environment, typically clear daylight with adequate visual cues
HH	Height [Altitude] Hold
HQ	Handling Qualities
HQR	Cooper-Harper Handling Qualities Rating
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
LPV	Localizer Performance with Vertical guidance
MTE	Mission-Task-Element, specifically refers to the maneuvers defined in 3.10
N/A	Not Applicable

$n_L(+)$	Positive load factor limit of the Operational Flight Envelope
$n_L(-)$	Negative load factor limit of the Operational Flight Envelope
OFE	Operational Flight Envelope
OGE	Out of Ground Effect
PDR	Preliminary Design Review – Early project milestone
Pf	Probability of encountering a failure, typically expressed as failures per flight hour
PH	Position Hold
PIO	Pilot-Induced Oscillation
RATE	Rate Response-Type
RCAH	Rate Command/Attitude Hold Response-Type
RCDH	[Yaw] Rate Command/Direction [Heading] Hold Response-Type
RCHH	[Vertical] Rate Command/Height [Altitude] Hold Response-Type
RPM	Revolutions per minute
SCAS	Stability and Control Augmentation System
SFE	Service Flight Envelope
SFR	Systems Functional Review – Early milestone in project evolution
S	Simulation method for verification
SVR	Systems Verification Review – Late milestone in project evolution
T	Test method for verification
TC	Turn Coordination
TRC	Translational Rate Command Response-Type
UCE	Usable Cue Environment
VCR	Visual Cue Rating
V_H	Maximum level flight airspeed at maximum continuous power
V_{mini}	Minimum approved airspeed for IFR
V_Y	Best rate-of-climb airspeed
✓	Specification requirement is applicable

6.2.2 Configurations
A configuration is defined by the external geometry. This includes the positions of variable systems such as landing gear or flaps, location of external stores and carriage of sling loads.

6.2.3 Degree of pilot attention
Some requirements depend on whether or not the pilot must attend to tasks other than flying the rotorcraft.

6.2.3.1 Fully attended operation
The pilot flying the rotorcraft can devote full attention to attitude and flight path control. Requirements for divided attention are minimal.

6.2.3.2 Divided attention operation
The pilot flying the rotorcraft is required to perform non-control-related sidetasks for a moderate period of time.

6.2.4 Flight Condition
Flight Condition is defined by a unique combination of the parameters which define the Operational Flight Envelope.

6.2.5 IMC operations
Instrument Meteorological Conditions (IMC) operations imply control of the rotorcraft solely with reference to the flight instruments. Occurs when the rotorcraft is clear of all obstacles.

6.2.6 Landing gear
Wheels or skids used to support the rotorcraft while on the ground.

6.2.7 Levels of handling qualities
Levels of handling qualities are defined by the 1 to 3, 4 to 6, and 7 to 8 ranges of the Cooper-Harper Handling Qualities Rating (HQR) Scale (Figure 1). This specification uses two distinct methods of establishing Levels of handling qualities, Predicted Levels and Assigned Levels. Predicted Levels are obtained by comparing the rotorcraft's flying qualities parameters with the boundaries appropriate to the rotorcraft's operational requirements. Assigned Levels are obtained from test pilots performing the designated MTEs. The results of these two methods are combined to determine the overall Level of handling qualities.

6.2.8 Load mass ratio
For externally slung loads, the load mass ratio is the ratio of external load mass to mass of rotorcraft plus external load.

6.2.9 Loadings
Loadings refer to the mass properties of a configuration and will be reflected in the total mass or weight, the center of gravity location, and the various moments of inertia.

6.2.10 Mission-Task-Element (MTE)
An element of a mission that can be treated as a handling qualities task.

6.2.11 Near-earth operations
Operations sufficiently close to the ground or fixed objects on the ground, or near water and in the vicinity of ships, oil derricks, etc., that flying is primarily accomplished with reference to outside objects.

6.2.12 Response-Type
A characterization of the rotorcraft response to a control input in terms of well recognized stability augmentation systems (i.e., Rate, Rate Command/Attitude Hold, etc.). However, it is not necessary to use a stability augmentation system to achieve the specified characteristics.

6.2.13 Rotorcraft Status
The Rotorcraft Status is defined by a unique combination of Configuration, Loading, Setting and State.

6.2.14 Settings
Settings refers to the selected functionality of rotorcraft components or systems that affect rotorcraft response, or UCE, which can be activated or deactivated by the pilot.

6.2.15 Speed ranges

6.2.15.1 Ground Speed
Ground speed is defined to be the speed with respect to a hover reference which may itself be moving, such as for shipboard operations.

6.2.15.2 Hover
Hovering flight is defined as all operations occurring at ground speeds less than 15 knots.

6.2.15.3 Low speed
Low-speed flight is defined as all operations occurring at ground speeds between 15 and 45 knots.

6.2.15.4 Forward flight
Forward flight is defined as all operations with a ground speed greater than 45 knots.

6.2.16 Stabilized hover
A stabilized hover is one in which there are no objectionable oscillations in rotorcraft attitude or position.

6.2.17 States
Rotorcraft States are Normal when the various systems are functioning as selected. Failure States exist when the functionality is modified by one or more malfunctions in rotorcraft components or systems that affect rotorcraft response or UCE.

6.2.18 Step input
A step input is defined as a rapid change in the controller force or position from one constant value to another. The input should be made as rapidly as possible without exciting undesirable structural or rotor modes, or approaching any rotorcraft safety limits. This differs from the classical definition, where the change occurs in zero time.

6.2.19 Winds
6.2.19.1 Calm winds
Winds with a steady component of less than 5 knots.

6.2.19.2 Light Winds
Winds with a steady component of between 10 and 15 knots.

6.2.19.3 Moderate winds
Winds with a steady component of between 20 and 35 knots.

6.3 Changes from Previous Issues
Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extent of the changes. Following are brief descriptions of the most significant changes in this revision.

6.3.1 Specifications, standards, and handbooks (2.2)
For the Standardization Document Order Desk, the online address has been provided.

6.3.2 Operational missions and Mission-Task-Elements (MTEs) (3.1.1)
A clarification was added for the MTEs in the DVE, that is, the procuring agency must define in the system specification the level of degraded visual environment for the selected MTEs. Is the DVE UCE=2 or UCE=3, as the level of necessary augmentation is very dependent on this distinction.

6.3.3 Assigned Levels of handling qualities (3.1.5.2)
This paragraph was modified by removing the external slung load guidance. A new paragraph (3.3.12) has been added to address the pitch and roll response to externally slung loads.

6.3.4 Interpretation of Predicted versus Assigned Levels of handling qualities (3.1.5.3)
This paragraph is new and was added to address a perceived problem where the aircraft passes all of the Level 1 criteria (predicted and assigned), except maybe one or two predicted criteria, and is subsequently labelled as a Level 2 aircraft.

6.3.5 Rotorcraft failures (3.1.14)
Recently, Ref. 1 provided recommendations on revisions to the Rotorcraft Failures section. The paper asserts that failures categorized by their effect on Levels of handling qualities should meet appropriate probability of failure targets as defined in SAE ARP-4761, and this should be included in ADS-33F-PRF. This aspect of ARP-4761 has been left out of ADS-33E-PRF intentionally. The Reference recommends changing step (a) from "Tabulate all rotorcraft failure states" by adding "and their associated failure

effects." This refers to the part of the safety analysis used by the FAA (in accordance with ARP-4761), wherein each failure is classified as Minor, Major, Severe Major, or Catastrophic. This is done by "safety experts." Once the failures are classified, the allowable probability of failure is defined. This process depends entirely on the interpretation of safety experts. This methodology is necessary for civil certifiers because the FAA does not have quantitative criteria with Level 1, 2, and 3 boundaries. The military specifications (e.g., ADS-33E-PRF) do have quantitative criteria boundaries, and in fact the Level 2 and Level 3 boundaries have been developed specifically to quantify the effect of degraded handling qualities such as occur during operation in a failed state. The requirement in ADS-33E-PRF eliminates the need for the subjective classification of failure states, which in fact is a major shortcoming of the FAA process. Never the less, the Rotorcraft Failures section in ADS-33E-PRF has been revised, eliminating the calculation of probability of encountering each identified failure state, and eliminating the calculation of total probabilities of encountering Level 2 and Level 3 flying qualities in the OFE, both of which belong in the system safety analysis. The Reference correctly notes that the Test Guide indicates that each failed state must be flight tested. This should be corrected in the Test Guide to state that the criterion parameters for each failed state must be calculated and plotted on the criterion boundaries to determine the Level associated with that failure.

6.3.6 Allowable Levels for Specific Failures (N/A)

Reference 1 suggested that setting a required Level regardless of failure probability is ambiguous. Hence, Allowable Levels for Specific Failures (3.1.14.2) and Rotorcraft Special Failure States (3.1.14.3) from ADS-33E-PRF have been eliminated.

6.3.7 Rotorcraft Special Failure States (N/A)

Reference 1 suggested that setting a required Level regardless of failure probability is ambiguous. Hence, Allowable Levels for Specific Failures (3.1.14.2) and Rotorcraft Special Failure States (3.1.14.3) from ADS-33E-PRF have been eliminated.

6.3.8 Specific Failures (N/A)

The Specific Failures section from ADS-33E-PRF was eliminated. The probability calculations in 3.1.14 should be used for all failures.

6.3.9 Transients following failures (3.1.14.1)

The requirements for transients following failures in Table III of ADS-33E-PRF had no supporting data. Hence, Table III has been eliminated and new criteria is provided. These criteria are adapted from the FAA requirements in Advisory Circular 29-2C Appendix B-7. The FAA methodology may not be perfect but is widely used and provides some assurance that the transient is not excessive.

6.3.10 Rotorcraft limits (3.1.15)

It has long been recognized that ADS-33E-PRF had no criteria for control margin. Experts agree that this should be included. Therefore, a 10% control margin throughout the OFE has been added.

6.3.11 Pilot-induced oscillations (N/A)

This somewhat global and difficult to assess compliance paragraph on pilot-induced oscillations (PIOs); hence, 3.1.16 from ADS-33E-PRF was eliminated. The prevention and assessment of PIOs shall be obtained by successfully meeting the quantitative requirements and the qualitative MTE evaluations in the specification.

6.3.12 Response-Types (3.2)

Based on industry feedback, the word "upgrade" was replaced by "another Response-Type." This will allow 'equivalent' Response-Types, that may not be an upgrade, but may provide superior or equivalent flying qualities to the specified Response-Type.

6.3.13 Required Response-Types (3.2.2)

See paragraph 6.3.12 above. In addition, if the requirements of Section 3.3 and 3.4 cannot be met for the equivalent Response-Type, one or more MTEs shall be selected and mutually agreed upon by the contractor and Government to ensure superior or equivalent flying qualities are achieved

6.3.14 Additional Level 1 requirement for Turn Coordination (3.2.2.2)

Based on an IFR simulation for the FAA (Ref. 2), the turn coordination requirements were added for single pilot IFR in forward flight.

6.3.15 Alternative for ACAH in Forward Flight (3.2.2.3)

The title of this section was changed from ADS-33E-PRF to include ACAH, rather than just Attitude Hold. In addition, based on the aforementioned IFR simulation, the words “single pilot IFR” were added.

6.3.16 Requirement for Autopilot (3.2.2.4)

The requirements for the autopilot were changed to include altitude hold and delete the ADS-33E-PRF requirement for coupling to the glideslope and localizer.

6.3.17 Response-Type ranking (3.2.3)

The second-row of Rate response combinations was modified to be more in alignment with the rest of the entries. That is, the ADS-33E-PRF height and position hold features were dropped, leaving the progression of rank ordering more linear. In addition, the words “higher rank” were replaced by “another Response-Type” (see paragraph 6.3.12 above).

6.3.18 Character of Rate and Rate Command Response-Types (3.2.6)

The definition was changed to what a Rate Response is, rather than all the responses that are not Attitude Command nor Translational Rate Command. Also, a definition for Rate Command was added.

6.3.19 Character of Attitude Hold and Heading Hold Response Types (3.2.7)

Original wording in ADS-33E-PRF was a bit mixed-up or confusing: “The peak attitude and heading excursions for this test shall vary from barely perceptible to at least 10 degrees,” but “shall return to within 10% of peak or one degree, whichever is greater.” So, the allowable error is always one degree, never 10% of peak, if the attitude change is not more than 10 degrees. This has been corrected to say, “shall return to within one degree for all attitude changes up to 10 degrees, and within 10% of peak attitude changes above 10 degrees. In addition, based on an IFR simulation in which the ADS-33E-PRF numbers were found to be much too lenient, the times to return to trim were reduced to within 10 seconds for UCE=1, and to within 7 seconds for UCE>1 or flight in IMC. Also, based on an IFR simulation (Ref. 2), a forward flight caveat was added for satisfying the requirements if after a disturbance, the trim airspeed returns at a prescribed rate and steady state is achieved with a damping ratio of 0.35.

6.3.20 Additional requirement for Heading Hold in Hover (3.2.7.1)

This requirement only applies in hover. Original wording requires that the heading reverse direction if the control input is removed abruptly. This requirement was based on an air-combat simulation. There is no supporting data in the Background Information User’s Guide (Ref. 3) and it is not desirable to have the heading reverse. Ingredients from the SAE AS94900A heading hold requirements have been incorporated.

6.3.21 Character of Attitude Command Response-Types (3.2.8)

Changes have been made to the definition, including some differences between hover/low-speed and forward flight. Based on an IFR simulation (Ref. 2), a forward flight caveat was added to account for airspeed command systems, which can be acceptable and yet, not meet the attitude command criteria. Also, changes have been incorporated to address trim changes and response to trim control. These recommendations were from the ADS-33 Test Guide (Ref. 4).

6.3.22 Character of Vertical Rate Command with Altitude (Height) Hold (3.2.10.1)

Four MTEs are referenced in this paragraph. The Sidestep MTE is only applicable to the Scout-Attack categories of rotorcraft. When this requirement is used for Utility and/or Cargo categories of rotorcraft, the Lateral Reposition MTE should be used instead of the Sidestep MTE. In addition, some clarification was added relative to maritime operations, i.e., holding altitude with respect to a mean flight deck deviation.

6.3.23 Short-term pitch and roll responses to disturbance inputs (3.3.2.2)

The ADS-33E-PRF requirements for short-term pitch and roll responses to disturbance inputs did not provide sufficient criteria. This problem has been known for some time and, in fact, new disturbance rejection bandwidth criteria were proposed and published in the Test Guide for ADS-33E-PRF (Ref. 4). See Ref. 4 for details on the criteria. Since the publication of the Test Guide, the Disturbance Rejection Bandwidth criteria has been expanded (Ref. 5) to cover not only rotorcraft pitch, roll, and yaw attitude-hold dynamics (3.3.2.2 and 3.3.5.2), but also the velocity- (3.3.9.4 and 3.3.11.1) and position-hold (3.3.9.5 and 3.3.10.1) dynamics. The DRB criteria are minimums. Upper limits on DRB are naturally capped at some point by stability margins and/or the disturbance rejection peak.

6.3.24 Mid-term response to control inputs (3.3.2.3)

The applicable range of frequencies for this criterion was expanded based upon recent knowledge and lessons learned (Ref. 6). The frequency range was changed from "all frequencies below the bandwidth frequency," to "all frequencies and for oscillations of all magnitudes that are noticeable to the pilot." Also, the test input was changed from "an abrupt controller input" to "a controller pulse input" to align other mid-term requirements. In addition, a sentence was added to cover the obvious: the lack of oscillations implies compliance.

6.3.25 Short-term response to yaw control inputs (bandwidth) (3.3.5.1)

The yaw bandwidth requirements in previous versions of ADS-33 were based on best available data and ground-based piloted simulation studies. Recently, a thorough in-flight simulation study (Ref. 7) was conducted and yielded new substantiation data for the yaw bandwidth requirements and the related yaw attitude quickness requirements. This data shows a substantial relaxation of the Level-boundaries is warranted. These recommendations have been incorporated in the yaw bandwidth criteria (3.3.5.1) and also the yaw attitude quickness criteria (3.3.6).

6.3.26 Short-term yaw response to disturbance inputs (3.3.5.2)

See paragraph 6.3.23 above. This paragraph was moved from its own section (3.3.7) in ADS-33E-PRF to a subparagraph under the small-amplitude yaw attitude changes heading.

6.3.27 Yaw rate response to lateral gusts (3.3.5.2.1)

This paragraph was moved from its own sub-section (3.3.7.1) in ADS-33E-PRF to a subparagraph under the small-amplitude yaw attitude changes paragraph.

6.3.28 Mid-term response to control inputs (3.3.5.3)

The changes incorporated into the pitch-roll mid-term response (3.3.2.3), i.e., the expansion of the applicable frequency range, was also incorporated into the yaw mid-term response requirements. In addition, a sentence was added to cover the obvious: the lack of oscillations implies compliance.

6.3.29 Moderate-amplitude heading changes (attitude quickness) (3.3.6)

See paragraph 6.3.25 above. The yaw attitude quickness requirements were changed based on the Ref. 7 flight test results.

6.3.30 Height response characteristics (3.3.9.1)

The off-axes guidance was changed from "pitch, roll, and heading excursions shall be maintained essentially constant" to "pitch, roll, and heading excursions shall be minimized."

6.3.31 Short-term vertical rate response to disturbance inputs (3.3.9.4)

See paragraph 6.3.23 above.

6.3.32 Short-term height response to disturbance inputs (3.3.9.5)

See paragraph 6.3.23 above.

6.3.33 Position Hold (3.3.10)

Based on lessons learned from the CH-47F DAFCS, the pitch and roll attitude excursions during the 360-degree turn was changed to include the words, "from trim." In addition, to improve clarification the requirement regarding the pitch and roll attitude response requirements was changed to "the command response shall meet the applicable response type" requirements. This broadens the scope to include not only attitude-command responses types, but also translational rate command response types. Also, since the wind requirements for selected MTEs was changed from Moderate to Light, the steady wind for demonstrating position hold during a 360-degree turn has been reduced from up to 35 knots to up to 15 knots. It is expected that the total wind component, including gusts, could be above 15 knots.

6.3.34 Short-term position response to disturbance (3.3.10.1)

See paragraph 6.3.23 above.

6.3.35 Translational Rate Response-Type (3.3.11)

Based on data from the CH-47F DAFCS, the TRC control sensitivity boundaries in Figure 17b have been called into question, as sensitivity in the Level 2 region has been assigned Level 1 ratings. Hence, a caveat was added to provide a means toward acceptance of a TRC control sensitivity that does not fall within the current Level 1 boundaries.

6.3.36 Short-term translational rate response to disturbance (3.3.11.1)

See paragraph 6.3.23 above.

6.3.37 Pitch (Roll) response to externally slung loads (3.3.12)

This is a new requirement. There has been many ground-based handling quality simulations to investigate external slung loads, with some of these simulations conducted in 1990s. More recently, there has been some flight test assessments. These have shown differences, and in some cases, difficulty in collecting/calculating external slung load handling quality parameters between flight and ground-based simulation. The new external slung load criteria (Ref. 8) captures the lessons learned from flight tests.

6.3.38 Mid-term response to control inputs (3.4.1.2)

The changes incorporated into the hover/low-speed pitch-roll mid-term response (3.3.2.3), i.e., the expansion of the applicable frequency range, was also incorporated into the forward flight pitch mid-term response requirements. In addition, a sentence was added to cover the obvious: the lack of oscillations implies compliance.

6.3.39 Longitudinal static stability (3.4.4)

A caveat has been added for compliance with this requirement if the pitch Attitude Command requirements are met.

6.3.40 Large-amplitude roll attitude changes (3.4.5.3)

The forward flight Moderate Agility row of Table IX was changed to be 'continuous' with the Moderate Agility row in the hover and low-speed requirement (Table VI). Flight data from performing the Slalom MTE in the GVE with various rotorcraft has shown roll rates and roll attitudes consistent with the hover/low-speed Moderate Agility large-amplitude roll requirements.

6.3.41 Linearity of roll response (N/A)

The requirements on linearity of the response to control inputs from ADS-33E-PRF has been removed. Linearity is not the issue, as nonlinear shaping can be favorable. The key word was "objectionable."

There are opportunities while conducting the MTE assessments for the pilot to comment on objectionable response characteristics.

6.3.42 Small-amplitude yaw response (bandwidth) (3.4.7.1)

The Forward flight small-amplitude yaw response (bandwidth) criteria has been changed to reflect recent flight test data results. The yaw bandwidth requirements in previous versions of ADS-33 were based on best available data and ground-based piloted simulation studies. Recently, a thorough in-flight simulation study (Ref. 7) was conducted and yielded new substantiation data for the yaw bandwidth requirements (and the related yaw attitude quickness requirements for Hover and Low-speed). This data shows a substantial relaxation of the Level-boundaries is warranted. These recommendations have been incorporated in the yaw bandwidth criteria (3.4.7.1) in Figure 26. Note, the ADS-33E-PRF version only contained forward-flight yaw bandwidth requirements for Target Acquisition and Tracking (TA&T) MTEs, whereas, there are now requirements for All other MTEs in addition to the TA&T MTEs.

6.3.43 Linearity of directional response (N/A)

See paragraph 6.3.41 above. For the same rationale, the ADS-33E-PRF linearity of directional response requirement has been removed.

6.3.44 Lateral-directional oscillations (3.4.8.1)

The word "oscillations" has been replaced by "inputs," i.e., requirements shall be met with "inputs" of any magnitude that might be experienced in operational use. In addition, a sentence was added to cover the obvious: the lack of oscillations implies compliance.

6.3.45 Lateral-directional characteristics in steady sideslips (3.4.9)

ADS-33E-PRF requirements were to be met with the rotorcraft trimmed for straight and *level* flight. Suggestions were made to include testing in climbs and/or descents. To focus, and yet potentially reduce the overall scope of testing, the tests should be conducted at the predicted worst flight conditions to meet these lateral-directional requirements with the aircraft trimmed for straight flight, whether that be in climbs/descents, or level flight.

6.3.46 Interaxis coupling (3.4.10)

The pitch and roll coupling requirement paragraphs from ADS-33E-PRF were collectively moved to an Interaxis coupling section following the individual pitch and roll requirements sections. In addition, the remaining pitch controller effectiveness throughout an autorotation was increased from 5% to 10%.

6.3.47 Pitch, roll, and yaw response to disturbance inputs (3.4.11)

See paragraph 6.3.23 above. The pitch, roll, and yaw attitude Disturbance Rejection Bandwidth criteria have been extended to forward flight.

6.3.48 Centering and breakout forces (3.6.1.1)

Removed caveat that collective breakout forces measured with adjustable friction set.

6.3.49 Active Inceptor cyclic dynamic characteristics (3.6.1.4)

Collaborative research on active inceptor systems (Ref. 9) has resulted in new dynamic requirements on these devices, establishing Level 1 'thumb-print' regions in natural frequency and damping for rate and attitude command response types.

6.3.50 Rotor start/stop (3.8.1)

Based on NAVAIR input, rotor start/stop coverage was expanded to include flight deck operations and recognize the rotorcraft-ship interface operating limits.

6.3.51 Shipboard operations (3.8.1.1)

Based on NAVAIR input, the shipboard operations criteria was altered to recognize the rotorcraft-ship interface operating limits.

6.3.52 Mission-Task-Elements (3.10)

There have been many ground-based simulation and flight test assessments using the Mission Task Elements (MTEs) in ADS-33E-PRF. Many of the lessons learned have been incorporated into the refinements included herein. One common lesson learned was the impact of winds on the MTEs. ADS-33E-PRF called for four MTEs to be evaluated in moderate winds (steady wind component of between 20 and 35 knots). These winds are now considered an 'extreme' condition. Test results have shown that even light winds (steady component of between 10 and 15 knots) can have an impact and degrade handling qualities. Hence, the moderate-wind requirement has been changed to light winds, recognizing the total total wind speed, with gusts, could be greater than the upper limit on a steady 15 knot component. This will still be a challenge. It must be recognized that some degradation in handling qualities will occur with stronger winds. Also, many of the Predicted quantitative requirements are dependent upon the Usable Cue Environment, that is, UCE=1 versus UCE>1. However, the Assigned qualitative MTE requirements are dependent upon the Good Visual Environment (GVE) versus the Degraded Visual Environment (DVE). The degree or level of DVE (i.e., UCE=2 or UCE=3) must be defined by the procuring agency for the selected MTEs. This distinction has been added to Operational missions and MTEs paragraph (3.1.1).

6.3.53 Hover (3.10.1)

The requirement to accomplish this MTE in moderate winds was changed to light winds. Also, the Scout/Attack adequate performance standards for longitudinal and lateral position in the DVE have been decreased from 8-ft to 6-ft, to better align with the other categories of rotorcraft. In addition, a note was added to reflect lessons learned from conducting testing on larger aircraft. The cargo-category performance standards are primarily from CH-47 flight tests. Testing from multiple simulations has shown the cargo/utility GVE standards for the time to attain a stabilized hover (5-sec for Desired; and 8-sec for Adequate) to be too short for larger aircraft, e.g., CH-53. These simulations have suggested 10- and 15-sec are more appropriated for the time to stabilize. Hence, a note was added to highlight these lessons learned. However, Government approval shall be obtained before designing/testing to these relaxed times.

6.3.54 Landing (3.10.2)

A Cargo/Utility category has been added and the touchdown performance standards have been increased. The tight touchdown requirements in ADS-33E-PRF may be appropriate for smaller rotorcraft, but for larger rotorcraft, the requirements have been found to be too tight. The increased touch down tolerances are more in line with prior versions of ADS-33, when the maneuver was a rapid vertical landing.

6.3.55 Slope Landing and Liftoff (3.10.3)

The name of this MTE was changed to better reflect that this maneuver also includes the liftoff, as well as the landing. This is also reflected in the no perceptible drift requirements. In addition, two changes were made to the adequate performance standards, making them the same as the desired standards: the time to maintain a level rotorcraft after initial ground contact was changed to 5-seconds; and the no perceptible drift at touchdown was changed from 'lateral and rearward' to 'horizontal' drift.

6.3.56 Hovering Turn (3.10.4)

In the maneuver description, a comment was added to allow evaluations in the left or right seat for cockpits with side-by-side seating. The wind requirement was changed from moderate to light. Also, the position tolerance for the adequate performance standard in completing the turn to a stabilized hover was changed from 'desired window' to the 'adequate window.'

6.3.57 Precision Load Placement (3.10.5)

This is a new MTE, that was developed and tested during the Ref. 10 flight tests in the GVE.

6.3.58 Pirouette (3.10.6)

The initial altitude was increased to 15 ft. In the maneuver description, a comment was added to allow evaluations in the left or right seat for cockpits with side-by-side seating. The wind requirement was changed from moderate to light. Also, in the description of the test course, the desired and adequate limits are defined for the hover reference point.

6.3.59 Vertical Maneuver (3.10.7)

The wind requirement was changed from moderate to light.

6.3.60 Depart/Abort (3.10.8)

In the maneuver description, the 40-50 knot groundspeed requirement from ADS-33E-PRF was dropped. It was found that desired performance could be achieved with groundspeeds less than 40 knots. The important parameter is the time to complete the 800-ft long maneuver, the speed will fall out. The altitude ceilings for desired and adequate performance were raised by 25 ft, to 75 and 100 ft respectively to provide more clearance for large rotorcraft.

6.3.61 Lateral Reposition (3.10.9)

In the maneuver description, the 35-knot groundspeed requirement from ADS-33E-PRF was dropped. It was found that desired performance could be achieved with groundspeeds less than 35 knots. The important parameter is the time to complete the 400-ft long lateral translation maneuver, the speed will fall out. Also, a comment was added to allow evaluations in the left or right seat for cockpits with side-by-side seating.

6.3.62 Slalom (3.10.10)

An objective has been added to the Slalom MTE to cover the DVE Slalom, which will be flown in the hover/low-speed regime. A note has been added relative to the 500-ft interval gate spacing. The Slalom MTE has been used in flight test assessments with many aircraft, including AH-64, Bo 105, CH-47, CH-53, and UH-60. From the CH-53G flight tests (Ref. 11), the 500-ft interval gate spacing was considered too tight, and the spacing was increased by 25 meters (to ~580 ft). These lessons learned are highlighted in a note, along with the need to obtain Government approval to use this expanded course. In addition, a note of clarification has been added regarding the reference altitude for rotorcraft with side-by-side rotors (i.e., tiltrotor).

6.3.63 Sidestep (3.10.13)

In the maneuver description, a comment was added to allow evaluations in the left or right seat for cockpits with side-by-side seating.

6.3.64 Transient Turn (3.10.15)

The Adequate altitude performance was increased by 100 ft, from 200 to 300 ft to harmonize the altitude standards between Desired and Adequate performance. In addition, tolerances were included for the wings-level attitude at maneuver completion.

6.3.65 Decelerating Approach (3.10.21)

Based on an IFR simulation for the FAA (Ref. 2), the maneuver description and performance standards for the Decelerating Approach, ILS Approach, and Missed Approach MTEs were changed and updated. For example, the ADS-33E-PRF Decelerating Approach version had glideslope and localizer performance in terms of feet, and the new requirements are in terms of dots on the glideslope and localizer cockpit instrument.

6.3.66 ILS or LPV Approach (3.10.22)

See paragraph 6.3.65 above. The name of this MTE was also modified to include Localizer Performance with Vertical guidance (LPV).

6.3.67 Missed Approach (3.10.23)

See paragraph 6.3.65 above.

6.3.68 Verification (4.0)

Table XV, which indicates the appropriate milestones for analysis, simulation, and flight tests, has been altered. The Pitch (Roll) Response to Externally Slung Loads (3.3.12) requirement was added. The Ditching characteristics (3.8.4) have been separated from Ground Handling (3.8), and the compliance through flight tests has been removed from the Ditching characteristics. Flight testing the ditching characteristics was deemed to be not practical and outside the scope of a handling qualities specification. Also, the requirement to perform the hover, hovering turn, pirouette, and vertical maneuver MTEs in moderate winds was changed to light winds.

6.3.69 References cited in 6.3

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10. Ivler, C.M., Powell, J.D., Tischler, M.B., Fletcher, J.W., and Ott, C.R., "Design and Flight Test of a Cable Angle/Rate Feedback Flight Control System for the RASCAL JUH-60 Helicopter," presented at the American Helicopter Society 68th Annual Forum, Fort Worth, TX, 1-3 May 2012.

11. Hoefinger, M. and Blanken, C.L., "Flight Testing the ADS-33E Cargo Helicopter Handling Qualities Requirements Using a CH-53G," *Journal of the American Helicopter Society*, Volume 58, Number 1, January 2013.

Table I. Mission-Task-Elements (MTEs)

MTE	REQUIRED AGILITY	ROTORCRAFT CATEGORY				EXTERNALLY SLUNG LOAD
		ATTACK	SCOUT	UTILITY	CARGO	
Tasks in GVE						
Hover	L	✓	✓	✓	✓	✓
Landing	L	✓	✓	✓	✓	
Slope Landing	L	✓	✓	✓	✓	
Hovering Turn	M	✓	✓	✓	✓	
Pirouette	M	✓	✓	✓	✓	
Vertical Maneuver	M	✓	✓	✓	✓	✓
Depart/Abort	M			✓	✓	✓
Lateral Reposition	M			✓	✓	✓
Slalom	M	✓	✓	✓	✓	
Vertical Remask	A	✓	✓			
Acceleration and Deceleration	A	✓	✓			
Sidestep	A	✓	✓			
Deceleration to Dash	A	✓	✓	✓		
Transient Turn	A	✓	✓	✓		
Pullup/Pushover	A	✓	✓	✓		
Roll Reversal	A	✓	✓	✓		
Turn to Target	T	✓	✓			
High Yo-Yo	T	✓	✓			
Low Yo-Yo	T	✓	✓			
Tasks in DVE						
Hover	L	✓	✓	✓	✓	✓
Landing	L	✓	✓	✓	✓	
Hovering Turn	L	✓	✓	✓	✓	
Pirouette	L	✓	✓	✓	✓	
Vertical Maneuver	L	✓	✓	✓	✓	✓
Depart/Abort	L			✓	✓	✓
Lateral Reposition	L			✓	✓	✓
Slalom	L	✓	✓	✓		
Acceleration and Deceleration	L	✓	✓			
Sidestep	L	✓	✓			
Tasks in IMC						
Decelerating Approach	L	✓	✓	✓	✓	✓
ILS Approach	L	✓	✓	✓	✓	
Missed Approach	L	✓	✓	✓	✓	
Speed Control	L	✓	✓	✓	✓	

Notes: ✓ = Suggested maneuvers to apply with appropriate performance standards.
L = Limited agility
M = Moderate agility
A = Aggressive agility
T = Target Acquisition and Tracking

Table II. Levels for Rotorcraft Failure States

PROBABILITY OF ENCOUNTERING	WITHIN OPERATIONAL FLIGHT ENVELOPE	WITHIN SERVICE FLIGHT ENVELOPE
Level 2 after failure	$< 2.5 \times 10^{-3}$ per flight hr	
Level 3 after failure	$< 2.5 \times 10^{-5}$ per flight hr	$< 2.5 \times 10^{-3}$ per flight hr
Loss of control	$< 2.5 \times 10^{-7}$ per flight hr	

Table III. Required Response-Types for hover and low speed – near earth

MTE	UCE = 1		UCE = 2		UCE = 3	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Required Response-Type for all MTEs. Additional requirements for specific MTEs are given below.	**RATE**	**RATE**	**ACAH**	**RATE + RCDH**	**TRC+RCDH + RCHH+PH**	**ACAH**
Hover			RCDH + RCHH			RCDH + RCHH
Landing			RCDH			RCDH
Slope landing			RCDH			RCDH
Hovering turn			RCHH			RCHH
Pirouette			RCHH			RCHH
Vertical Maneuver			RCDH			RCDH
Depart/Abort			RCDH + RCHH			RCDH + RCHH
Lateral Reposition			RCDH + RCHH			RCDH + RCHH
Slalom			RCHH			RCHH
Vertical remask			RCDH			RCDH
Acceleration and deceleration			RCDH + RCHH			RCDH + RCHH
Sidestep			RCDH + RCHH			RCDH + RCHH
Turn to target			RCDH + RCHH			RCDH + RCHH
Divided attention required	RCDH + RCHH + PH		RCDH + RCHH			RCDH + RCHH

Table IV. Required Response-Types for forward flight (pitch and roll)

MTE	VMC		IMC and UCE = 2,3	
	Level 1	Level 2	Level 1	Level 2
Single Pilot IFR	N/A	N/A	ACAH or Autopilot	RCAH
Dual Pilot IFR	N/A	N/A	RCAH	Rate
Divided attention required (single pilot operation in high workload VMC)	ACAH	RCAH	N/A	N/A
Slalom	Rate	Rate	N/A	N/A
Deceleration to Dash	Rate	Rate	N/A	N/A
Transient Turn	Rate	Rate	N/A	N/A
Pullup/Pushover	Rate	Rate	N/A	N/A
Roll Reversal	Rate	Rate	N/A	N/A
High Yo-yo	Rate	Rate	N/A	N/A
Low Yo-yo	Rate	Rate	N/A	N/A

Table V. Requirements for Disturbance Rejection Bandwidth (DRB) and Peak (DRP) – hover and low speed

	AXIS		
	Pitch (θ)	Roll (ϕ)	Yaw (ψ)
DRB (rad/sec) $\geq$	0.5	0.9	0.7
DRP (dB) $\leq$	5.0	5.0	5.0
	Surge (u)	Sway (v)	Heave (w)
DRB (rad/sec) $\geq$	0.34	0.54	1.0
DRP (dB) $\leq$	5.0	5.0	5.0
	Axial (x)	Lateral (y)	Vertical (z)
DRB (rad/sec) $\geq$	0.17	0.17	0.17
DRP (dB) $\leq$	3.0	3.0	3.0

Table VI. Requirements for large-amplitude attitude changes – hover and low speed

AGILITY CATEGORY MTE	RATE RESPONSE-TYPES						ATTITUDE RESPONSE-TYPES			
	ACHIEVABLE ANGULAR RATE (deg/sec)						ACHIEVABLE ANGLE (deg)			
	LEVEL 1			LEVELS 2 AND 3			LEVEL 1		LEVELS 2 AND 3	
	Pitch	Roll	Yaw	Pitch	Roll	Yaw	Pitch	Roll	Pitch	Roll
Limited Agility Hover Landing Slope Landing	±6	±21	±9.5	±3	±15	±5	±15	±15	±7	±10
Moderate Agility Hovering Turn Pirouette Vertical Maneuver Depart/Abort Lateral Reposition Slalom	±13	±50	±22	±6	±21	±9.5	+20 -30	±60	±13	±30
Aggressive Agility Vertical Remask Acceleration Deceleration Sidestep Target Acquisition and Track Turn to Target	±30	±50	±60	±13	±50	±22	±30	±60	+20 -30	±30

Table VII. Maximum values for height response parameters – hover and low speed

LEVEL	$T_{\dot{h}_{eq}}$ (sec)	$\tau_{\dot{h}_{eq}}$ (sec)
1	5.0	0.20
2	∞	0.30

Table VIII. Maximum values for flight path response parameters – forward flight

LEVEL	$T_{\dot{h}_{eq}}$ (sec)	$\tau_{\dot{h}_{eq}}$ (sec)
1	5.0	0.20
2	10.0	0.30

Table IX. Requirements for large-amplitude roll attitude changes – forward flight

AGILITY CATEGORY MTE	RATE RESPONSE-TYPES ACHIEVABLE ROLL RATE (deg/sec) LEVEL 1	RATE RESPONSE-TYPES ACHIEVABLE ROLL RATE (deg/sec) LEVEL 2	ATTITUDE RESPONSE-TYPES ACHIEVABLE BANK ANGLE (deg) LEVEL 1	ATTITUDE RESPONSE-TYPES ACHIEVABLE BANK ANGLE (deg) LEVEL 2
<u>Limited Agility</u> Decel Approach in IMC ILS Approach Missed approach Speed Control	±15	±12	±25	±15
<u>Moderate Agility</u> Slalom	±50	±21	±60	±30
<u>Aggressive Agility</u> Deceleration to Dash Transient Turn Pullup/Pushover Roll Reversal	±50	±21	±90	±30
<u>Target Acquisition and Track</u> High Yo-yo Low Yo-yo	±90	±50	Unlimited	±60

Table X. Requirements for Disturbance Rejection Bandwidth (DRB) and Peak (DRP) – forward flight

	AXIS		
	Pitch (θ)	Roll (ϕ)	Yaw (ψ)
DRB (rad/sec) ≥	0.5	0.9	0.7
DRP (dB) ≤	5.0	5.0	5.0

Table XI. Allowable breakout forces, pounds – hover and low speed

COCKPIT CONTROL	LEVEL 1 min/max	LEVEL 2 min/max	LEVEL 3 max
Pitch (Centerstick)	0.5/1.5	0.5/3.0	6.0
Roll (Centerstick)	0.5/1.5	0.5/2.0	4.0
Yaw (Pedals)	2.0/7.0	1.0/7.0	14.0
Collective	1.0/3.0	0.75/4.5	6.0

Table XII. Allowable breakout forces, pounds – forward flight

COCKPIT CONTROL	CARGO min	CARGO max
Pitch (Centerstick)	0.5	5.0
Roll (Centerstick)	0.5	4.0
Yaw (Pedals)	2.0	14.0

NOTE: The values in Table XII are for Levels 1 and 2.
For Level 3 the maximum values may be doubled.

Table XIII. Allowable control force gradients, pounds/inch

COCKPIT CONTROL	LEVEL 1		LEVEL 2	
	min	max	min	max
Pitch	0.5	3.0	0.5	5.0
Roll	0.5	2.5	0.5	5.0
Yaw	3.0	10.0	2.0	20.0

Table XIV. Limit cockpit control forces, pounds

COCKPIT CONTROL	HOVER AND LOW SPEED			FORWARD FLIGHT		
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 1	LEVEL 2	LEVEL 3
Pitch (Centerstick)	15.0	20.0	40.0	30.0	35.0	40.0
Roll (Centerstick)	10.0	15.0	20.0	15.0	20.0	25.0
Yaw (Pedals)	30.0	40.0	80.0	75.0	100.0	125.0
Collective	10.0	10.0	10.0	10.0	10.0	10.0

Table XV. Requirements/verification matrix

PARAGRAPH NO.	REQUIREMENT	VERIFICATION METHOD/EVENT				
		SFR	PDR	CDR	FFR	SVR
3.1.14	Rotorcraft Failures	A	A	A	S	T
3.1.15	Rotorcraft Limits			A	S	F
3.1.16	Residual Oscillations					F
3.2.2	Required Response-Type	A	T	T	T	F
3.3	Hover and Low Speed					
3.3.1	Equilibrium Characteristics		A	A	A	F
3.3.2	Small-Amplitude Pitch (Roll) Attitude	A	A	A	A	F
3.3.3	Moderate-Amplitude Pitch (Roll) Attitude Changes	A	A	A	A	F
3.3.4	Large-Amplitude Pitch (Roll) Attitude Changes	A	A	A	A	F
3.3.5	Small-Amplitude Yaw Attitude Changes	A	A	A	A	F
3.3.6	Moderate-Amplitude Heading Changes	A	A	A	A	F
3.3.7	Large-Amplitude Heading Changes	A	A	A	A	F
3.3.8	Interaxis Coupling		A	A	A	F
3.3.9	Response to Collective Controller	A	A	A	A	F
3.3.10	Position Hold		A	A	A	F
3.3.11	Translational Rate Response-Type		A	A	A	F
3.3.12	Pitch (Roll) Response to Externally Slung Loads		A	A	A	F
3.4	Forward Flight					
3.4.1	Pitch Attitude Response to Longitudinal Controller	A	A	A	A	F
3.4.2	Pitch Control Power	A	A	A	A	F
3.4.3	Flight Path Control				A	F
3.4.4	Longitudinal Static Stability	A	A	A	A	F
3.4.5	Roll Attitude Response to Lateral Controller	A	A	A	A	F
3.4.6	Roll-Sideslip Coupling		A	A	A	F
3.4.7	Yaw Response to Yaw Controller	A	A	A	A	F
3.4.8	Lateral-Directional Stability	A	A	A	A	F
3.4.9	Lateral-Directional Characteristics in Sideslips		A	A	A	F
3.4.10	Interaxis Coupling		A	A	A	F
3.4.11	Pitch, Roll, Yaw Responses to Disturbances		A	A	A	F
3.6	Controller Characteristics	A	A	S	T	F
3.7	Transfer Between Response-Types		A	A	S	F
3.8	Ground Handling		A	A	A	F
3.8.4	Ditching characteristics		A	A	A	A
3.9	Requirements for Externally Slung Loads				A	T
3.10	Mission-Task-Elements			S	S	F

Methods of Verification:
- A – Analysis
- S - Piloted Simulation
- F - Flight Test
- T - Testing, miscellaneous

Events:
- SFR - System Functional Review
- PDR - Preliminary Design Review
- CDR - Critical Design Review
- FFR - First Flight Readiness Review
- SVR - System Verification Review

Table XVI. Rotorcraft status and flight conditions for verification

<table>
<tr><th rowspan="2">HQ LEVEL REQD</th><th colspan="4">ROTORCRAFT STATUS</th><th rowspan="2">FLIGHT CONDITIONS</th><th colspan="2">REQTS TO BE SATISFIED</th></tr>
<tr><th>CONFIG-URATIONS</th><th>LOADINGS</th><th>SETTINGS</th><th>STATES</th><th>FQ CRITERIA</th><th>APPLIC-ABLE MTE</th></tr>
<tr><td rowspan="2">1</td><td rowspan="9">As required by the operational missions</td><td rowspan="9">Possible range for applicable configurations</td><td>Primary SCAS</td><td rowspan="3">Normal and Pf >2.5x10^{-3}</td><td>GVE OFE</td><td rowspan="8">All for rotorcraft category</td><td rowspan="5">All for mission</td></tr>
<tr><td>Primary or Augmented SCAS</td><td rowspan="2">DVE OFE</td></tr>
<tr><td rowspan="2">2</td><td>Primary SCAS</td></tr>
<tr><td rowspan="2">Secondary SCAS</td><td rowspan="2">Normal and Pf >2.5x10^{-5}</td><td>GVE OFE</td></tr>
<tr><td>3</td><td>DVE OFE</td></tr>
<tr><td rowspan="2">2</td><td>Primary SCAS</td><td>Normal</td><td>GVE SFE</td><td rowspan="2">N/A</td></tr>
<tr><td>Primary or Augmented SCAS</td><td>Normal</td><td>DVE SFE</td></tr>
<tr><td>3</td><td rowspan="2">Backup</td><td rowspan="2">Pf >2.5x10^{-7}</td><td>GVE</td><td>NOE Egress</td></tr>
<tr><td>Con-trol-lable</td><td>DVE</td><td>N/A</td><td>Up-&-away egress</td></tr>
</table>

Pf = Probability of encountering a failure per flight hour.

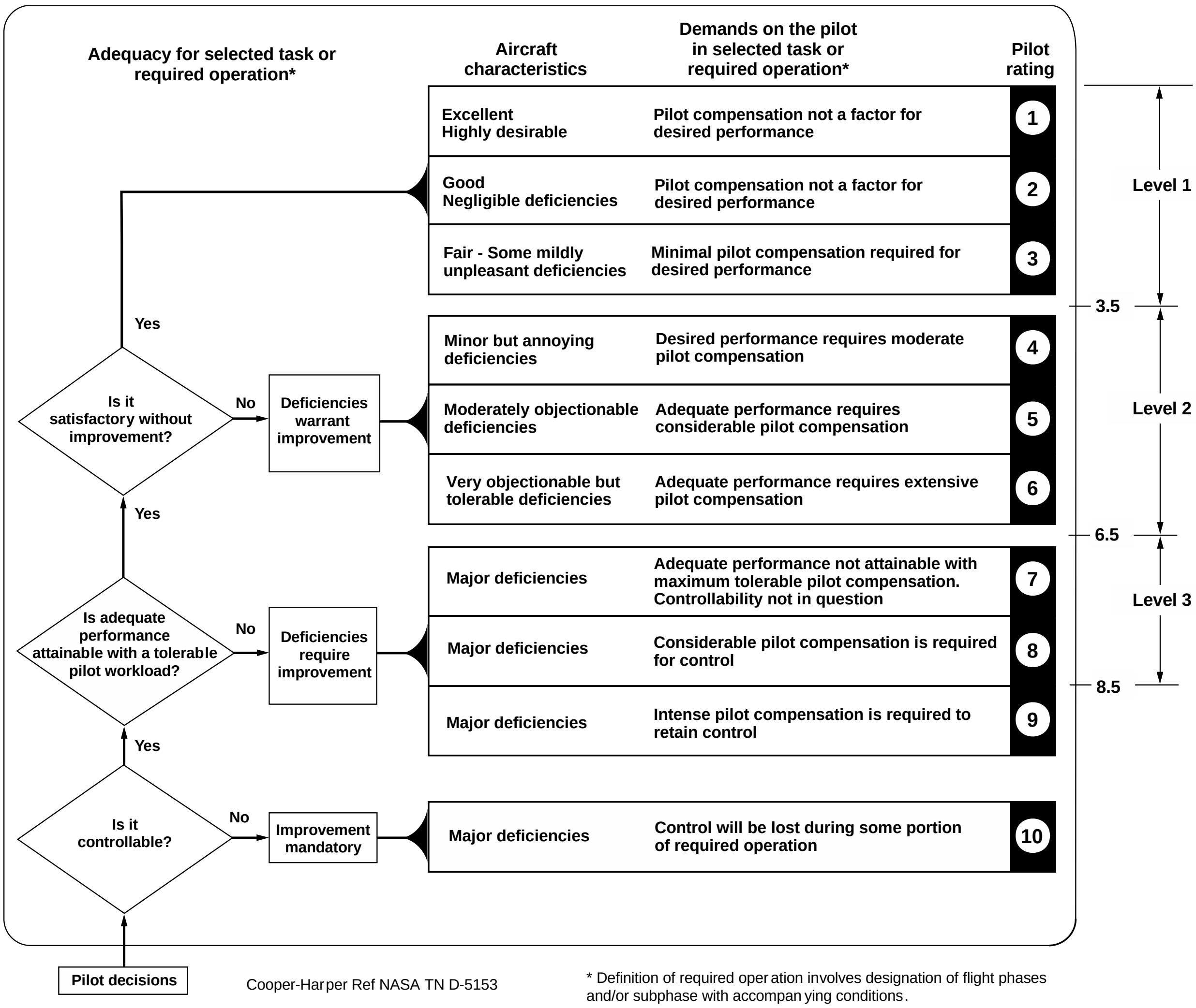
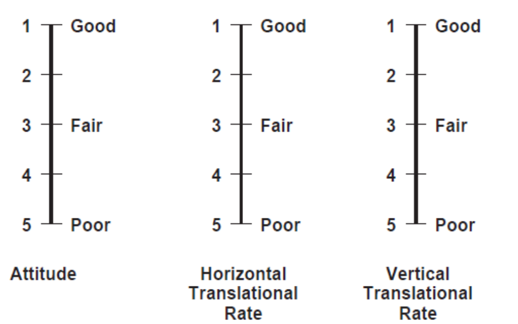


Figure 1. Definition of handling qualities Levels



Pitch, roll and yaw attitude, and lateral-longitudinal, and vertical translational rates shall be evaluated for stabilization effectiveness according to the following definitions:

Good : Can make aggressive and precise corrections with confidence and precision is good.

Fair : Can make limited corrections with confidence and precision is only fair.

Poor: Only small and gentle corrections are possible, and consistent precision is not attainable.

Figure 2. Visual cue rating scale

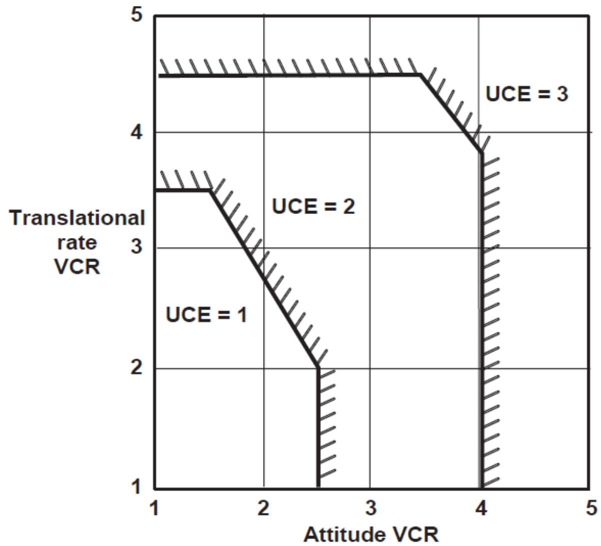


Figure 3. Usable Cue Environments for Visual Cue Ratings

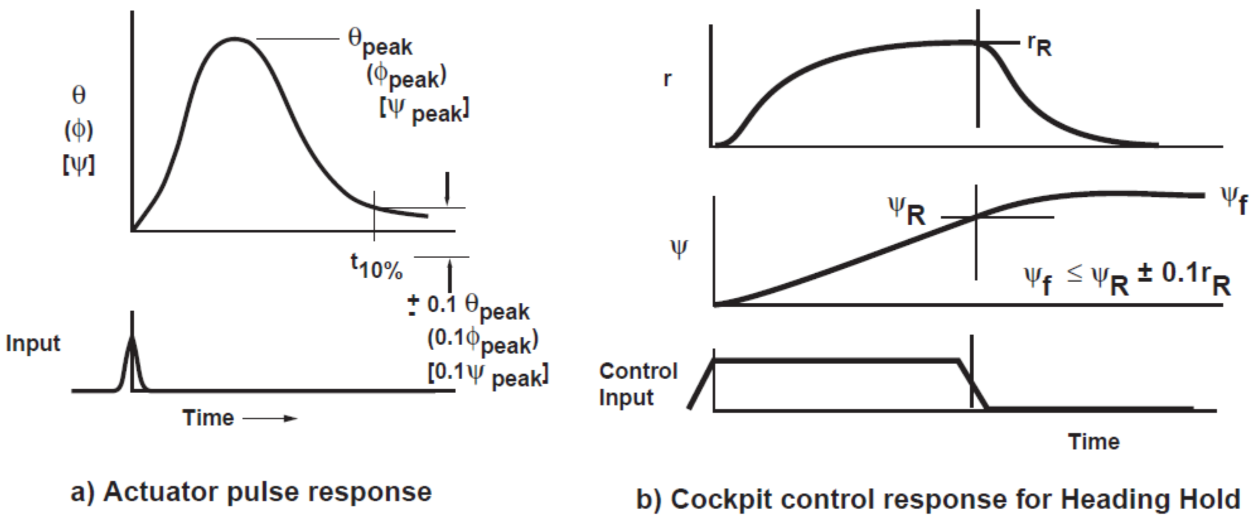
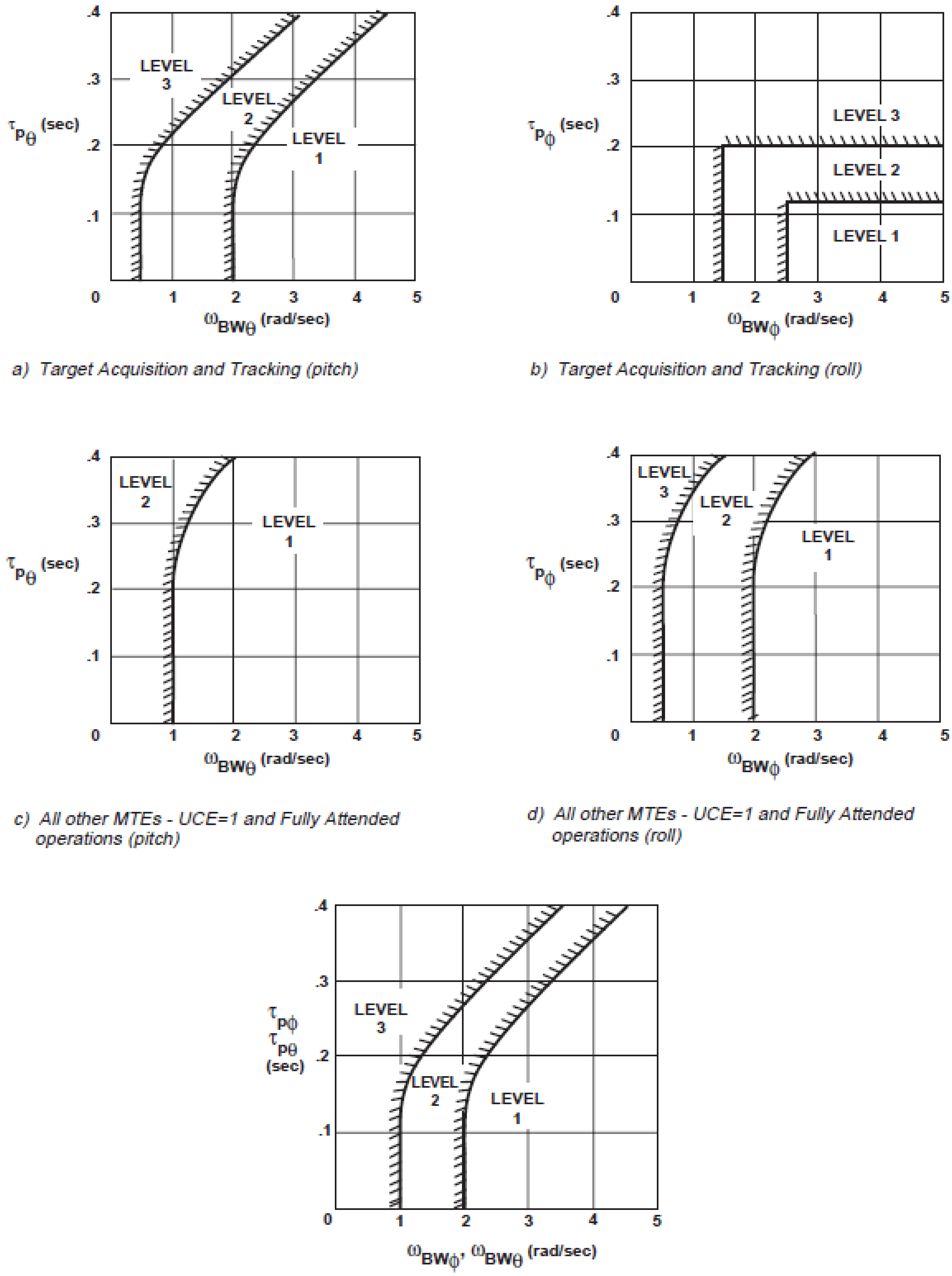


Figure 4. Responses for Attitude Hold and Heading Hold Response Types



a) *Target Acquisition and Tracking (pitch)*

b) *Target Acquisition and Tracking (roll)*

c) *All other MTEs - UCE=1 and Fully Attended operations (pitch)*

d) *All other MTEs - UCE=1 and Fully Attended operations (roll)*

e) *All other MTEs - UCE > 1 and/or Divided Attention operations (pitch and roll)*

Figure 5. Requirements for small-amplitude pitch (roll) attitude changes – hover and low speed

Phase delay:

$$\tau_p = \frac{\Delta\Phi 2\omega_{180}}{57.3\,(2\omega_{180})}$$

Note: If phase is nonlinear between ω_{180} and $2\,\omega_{180}$, τ_p shall be determined from a linear least squares fit to phase curve between ω_{180} and $2\,\omega_{180}$

Caution:

For ACAH, if $\omega_{BW_{gain}} < \omega_{BW_{phase}}$, or if $\omega_{BW_{gain}}$ is indeterminate, the rotorcraft may be PIO prone for super-precision tasks or aggressive pilot technique.

Rate response-types:

ω_{BW} is lesser of $\omega_{BW_{gain}}$ and $\omega_{BW_{phase}}$

Attitude Command/Attitude Hold Response-Types (ACAH):

$\omega_{BW} = \omega_{BW_{phase}}$

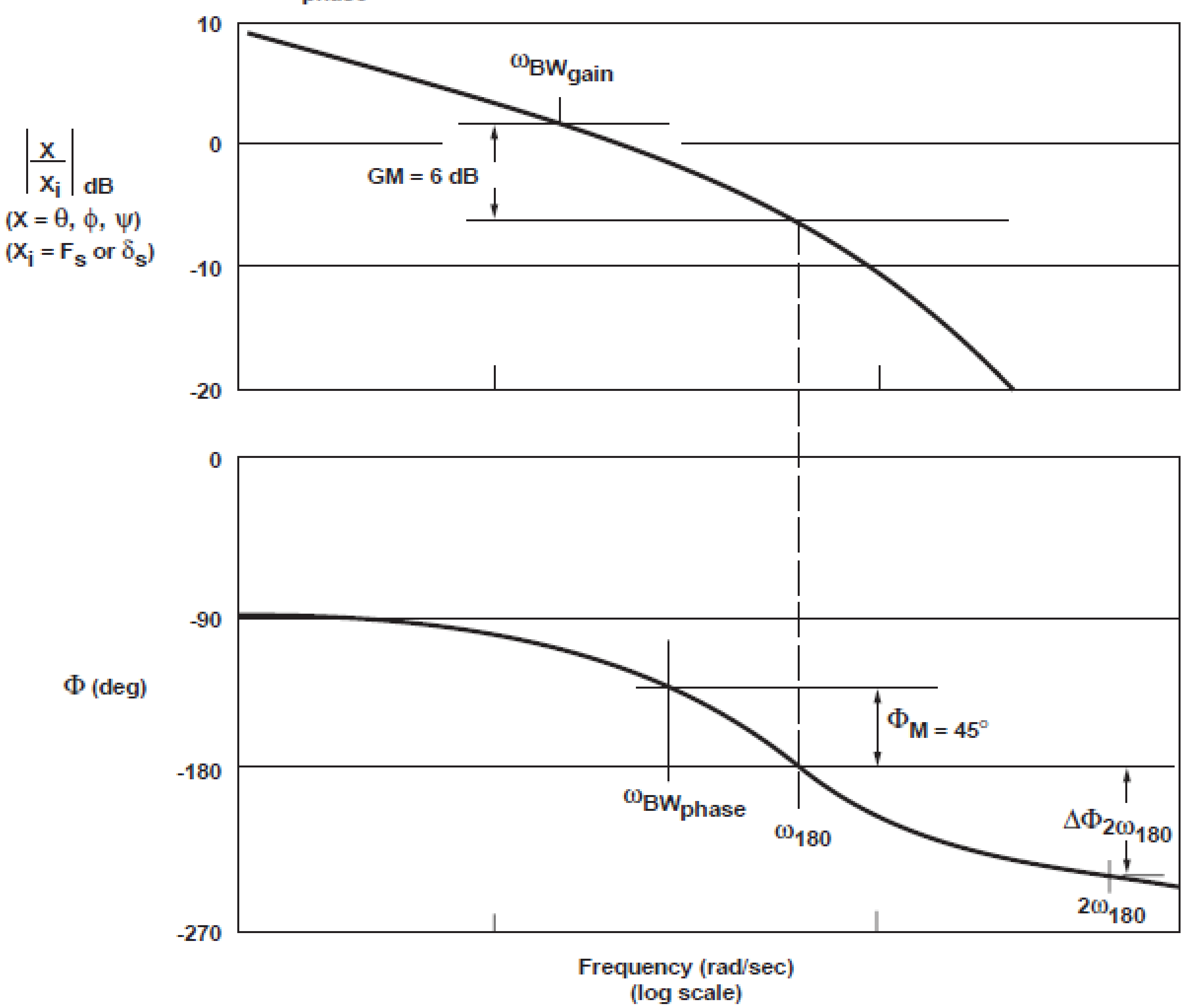
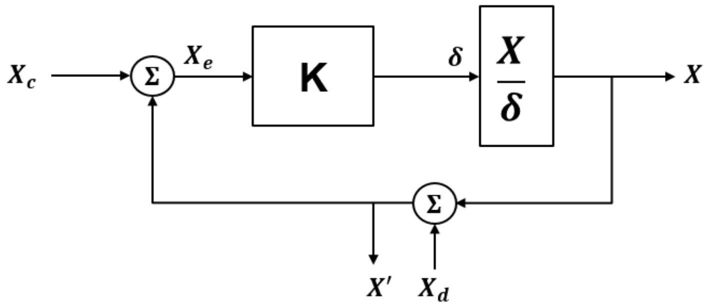


Figure 6. Definitions of bandwidth and phase delay

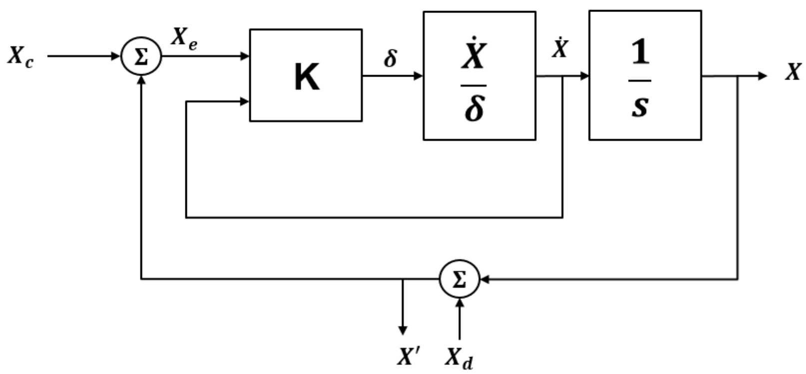


DRB/DRP calculated from magnitude of X'/X_d frequency response

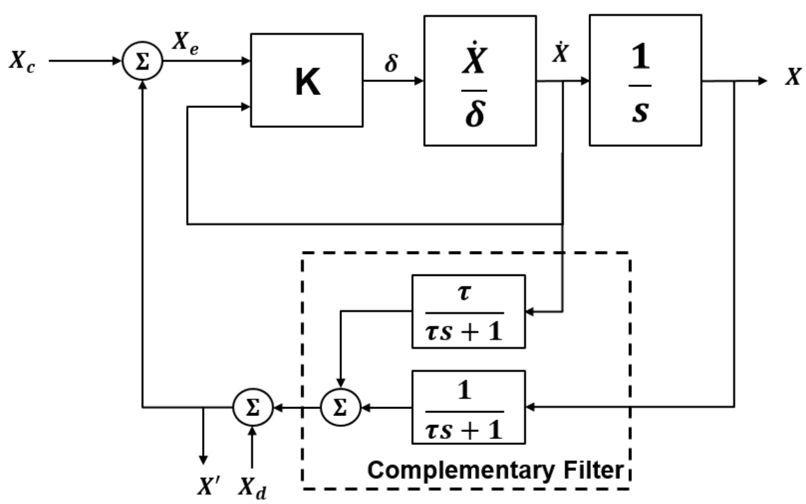
Alternatively:

$$\left|\frac{X'}{X_d}\right|_{reconstructed} = 1 - \left|\frac{X}{X_c}\right| = 1 + \left|\frac{X}{X_d}\right| \qquad (X = \phi, \theta, \psi, u, v, w, x, y, \text{or } z)$$

a) Disturbance rejection block diagram



b) Disturbance rejection block diagram with multiple feedbacks



c) Disturbance rejection block diagram with multiple feedbacks and hold variable complementary filter

Figure 7. Disturbance rejection block diagrams

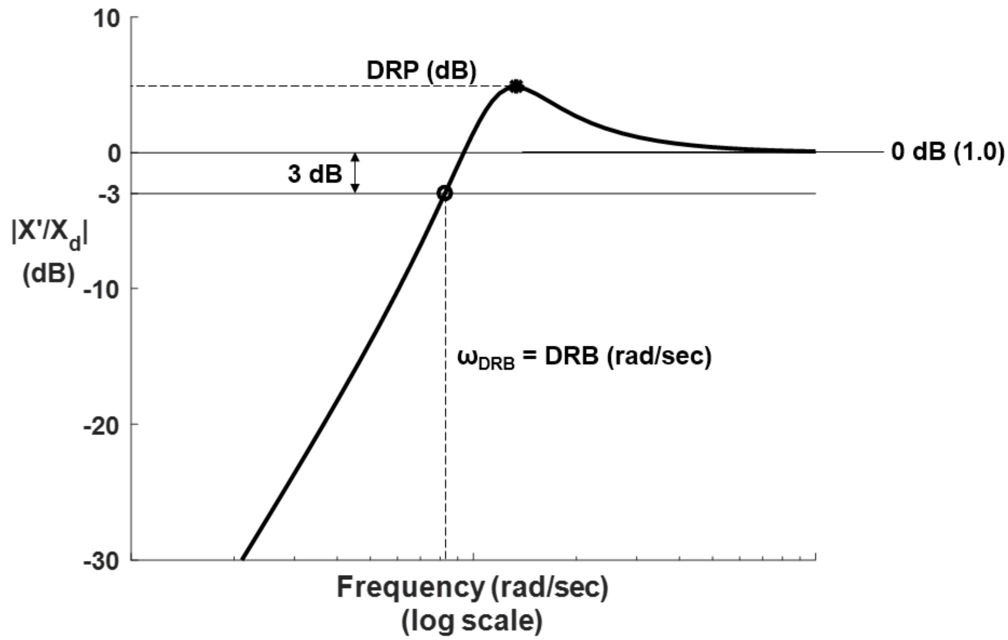


Figure 8. Definition of Disturbance Rejection Bandwidth (DRB) and Peak (DRP)

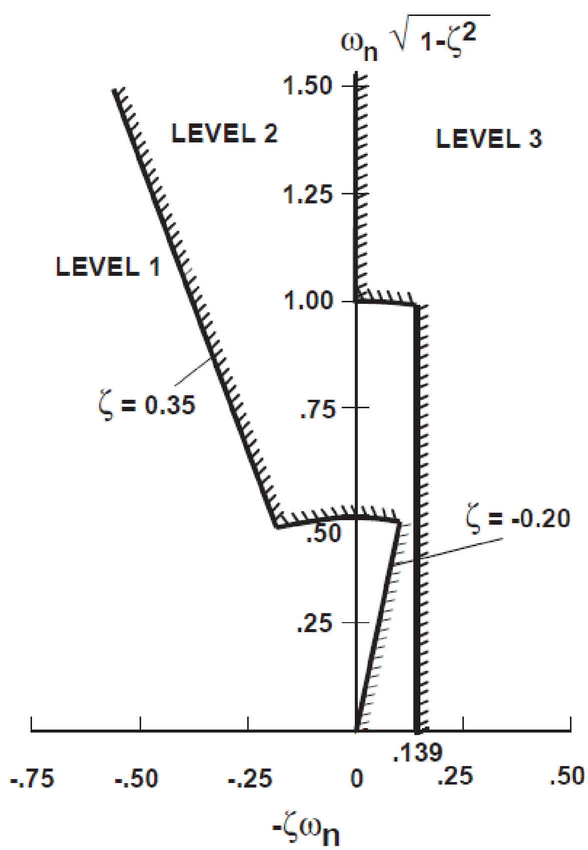
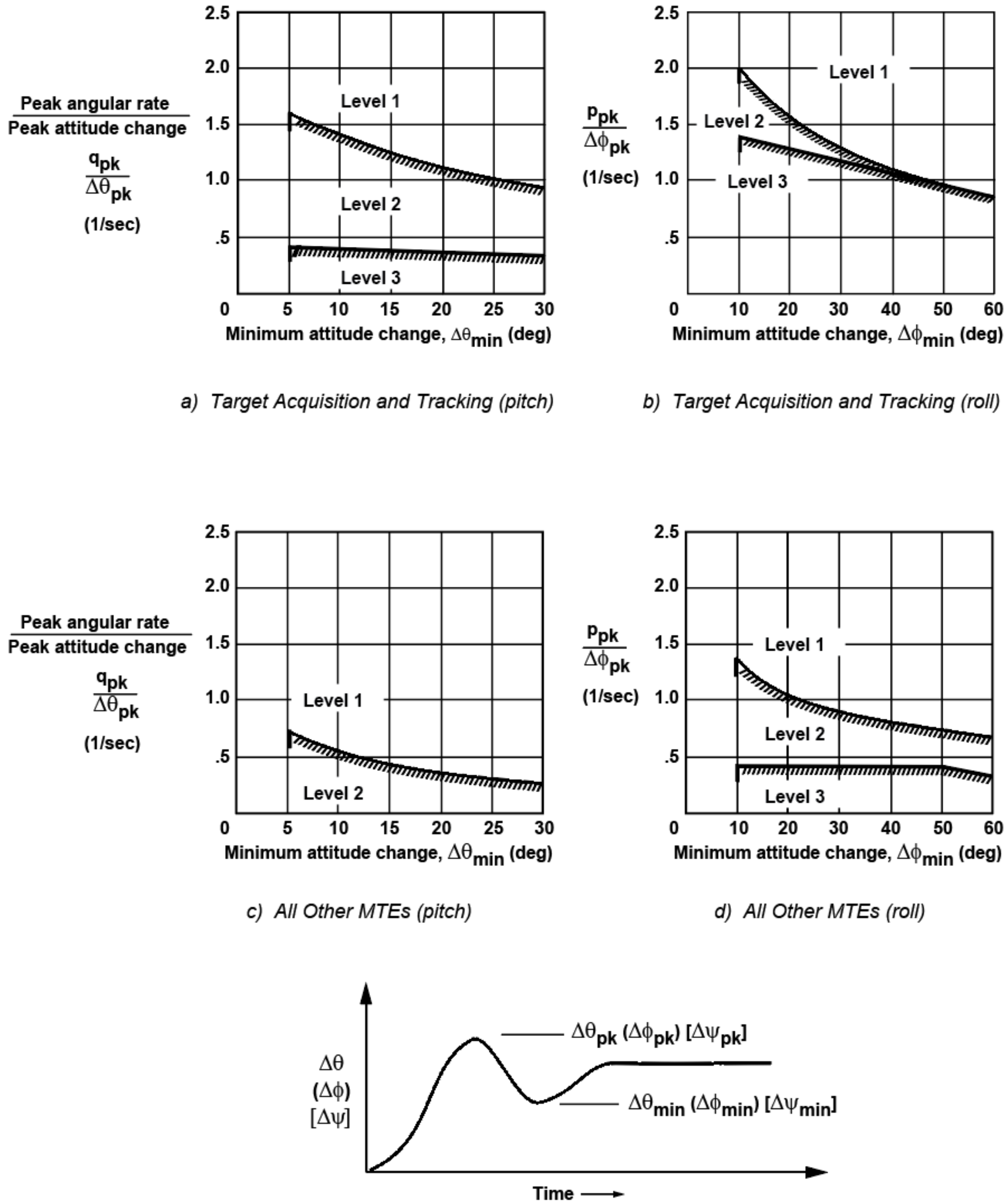


Figure 9. Limits on pitch (roll) oscillations – hover and low speed



a) Target Acquisition and Tracking (pitch)

b) Target Acquisition and Tracking (roll)

c) All Other MTEs (pitch)

d) All Other MTEs (roll)

e) Definition of Moderate-Amplitude Criterion Parameters

Figure 10. Requirements for moderate-amplitude pitch (roll) attitude changes – hover and low speed

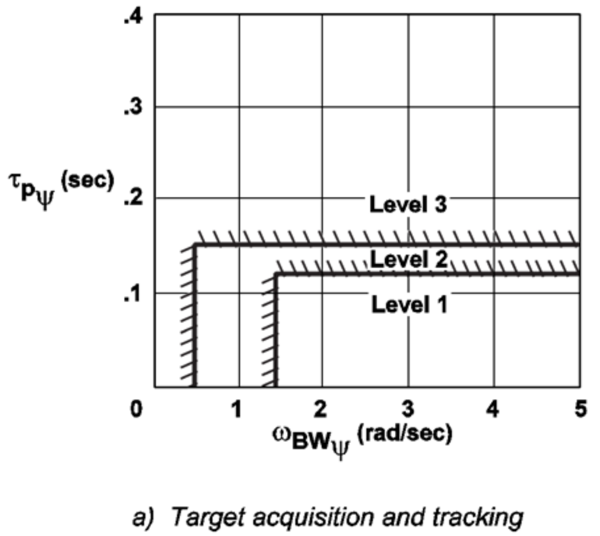


Figure 11. Requirements for small-amplitude heading changes – hover and low speed

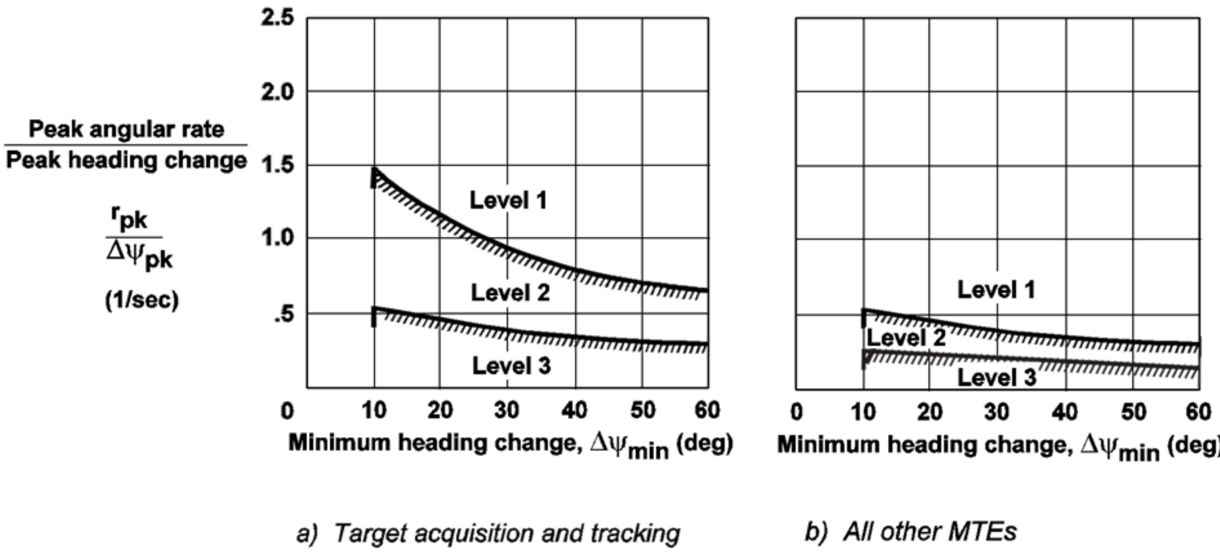
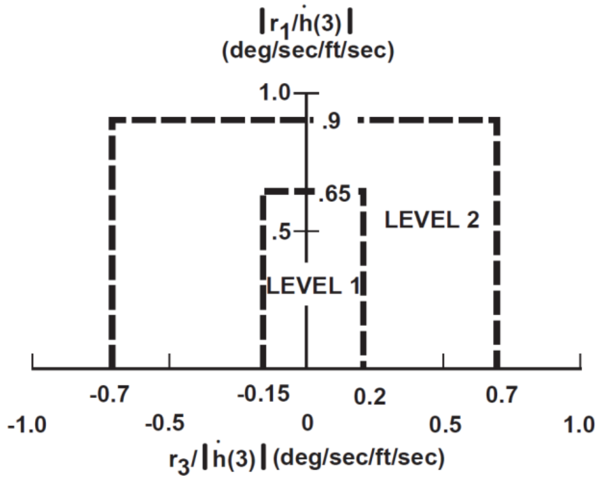


Figure 12. Requirements for moderate-amplitude heading changes – hover and low speed



Where:

r_1 = first peak (before 3 seconds) or r(1) if no peak occurs before 3 seconds

r_3 = r(3) – r_1 for $r_1 > 0$, or r_1 – r(3) for $r_1 < 0$

r(1) and r(3) are yaw rate responses measured at t = 1 and 3 seconds, respectively, following a step collective input at t = 0

In the unlikely event of more than one peak before 3 seconds, the largest peak (by magnitude) should be designated as r_1

Figure 13. Yaw-due-to-collective coupling requirements

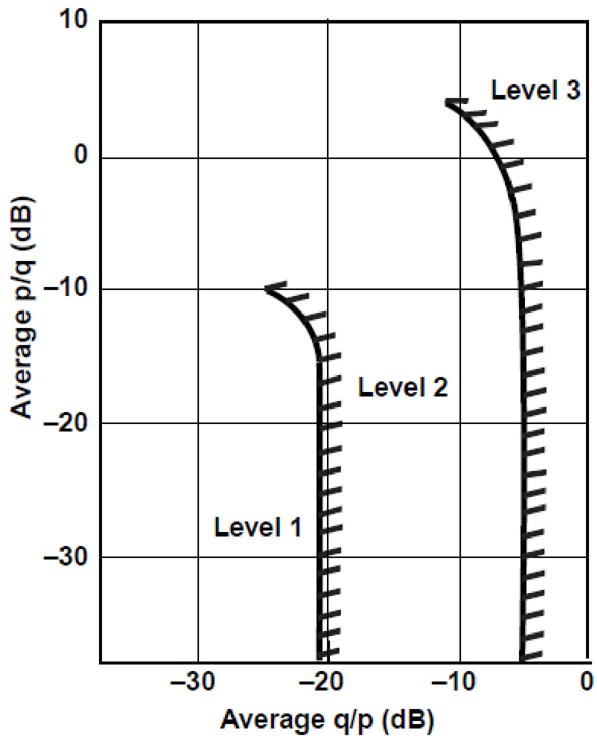


Figure 14. Requirements for pitch due to roll and roll due to pitch coupling for Target Acquisition and Tracking

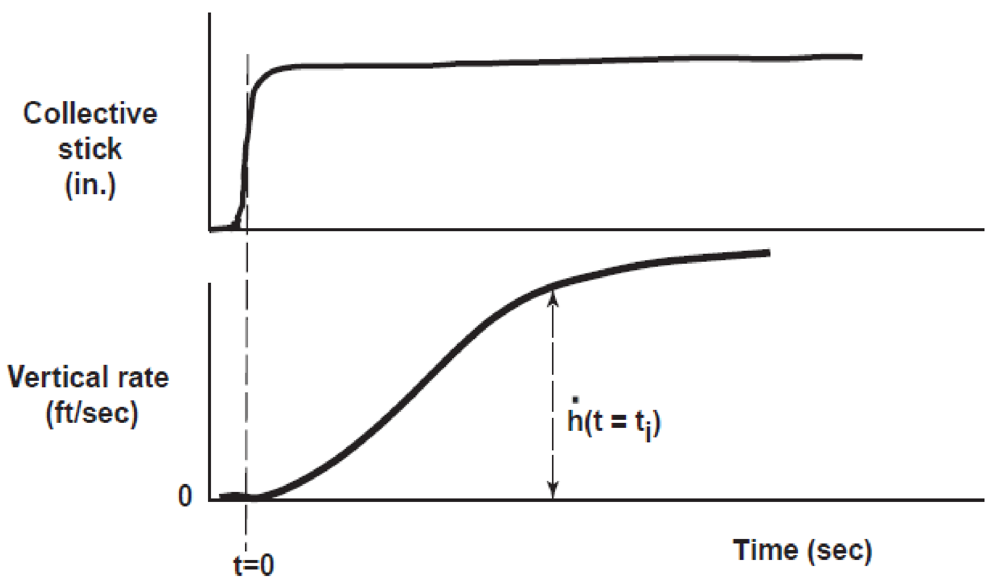
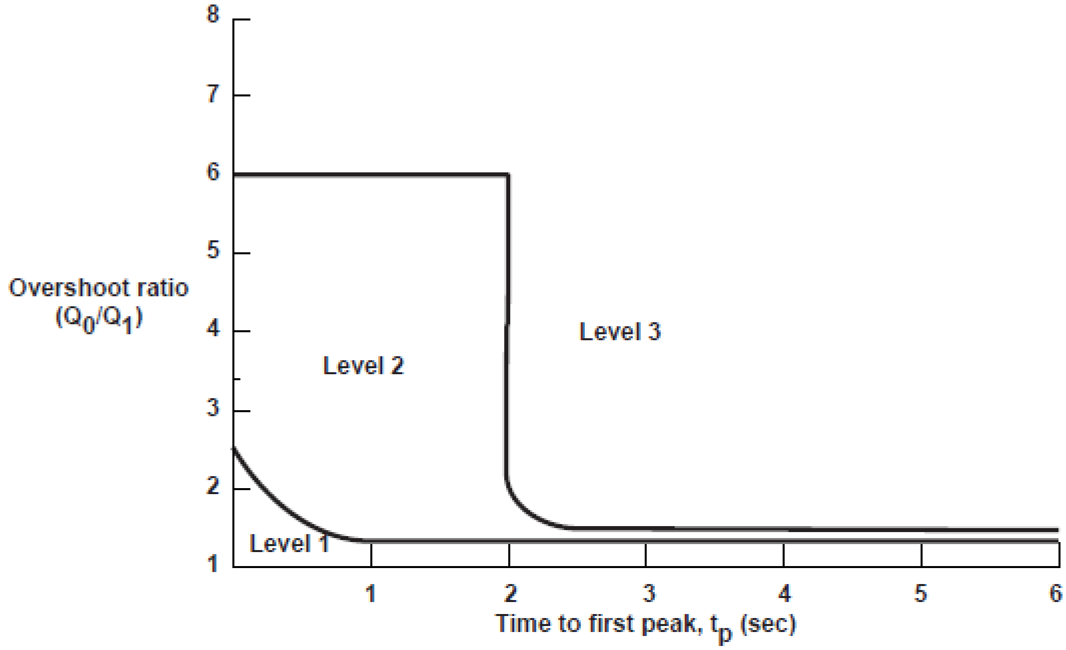
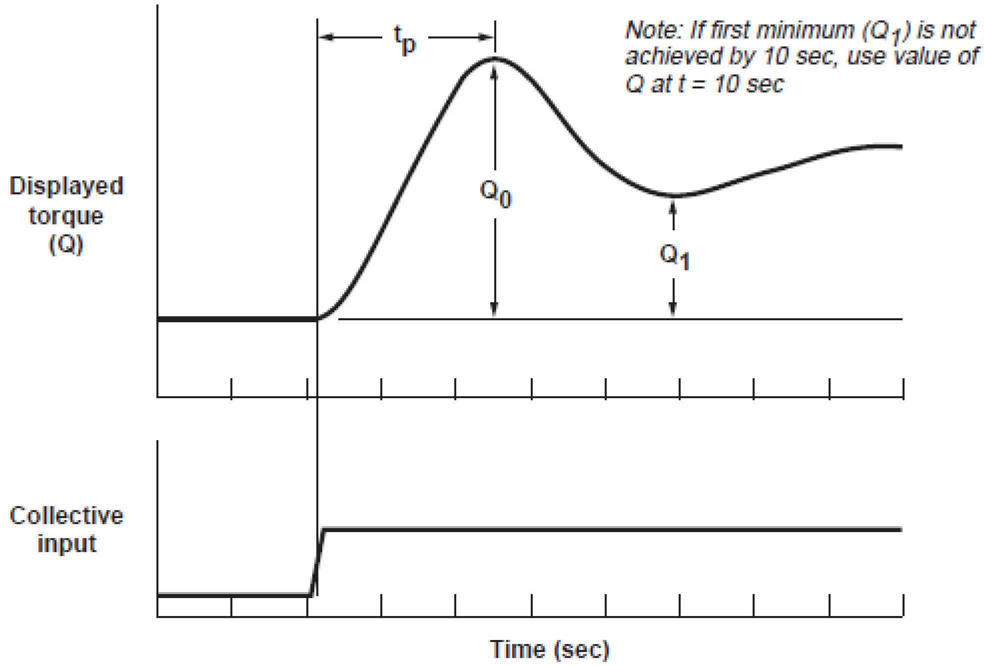


Figure 15. Procedure for obtaining equivalent time domain parameters for the height response to collective controller

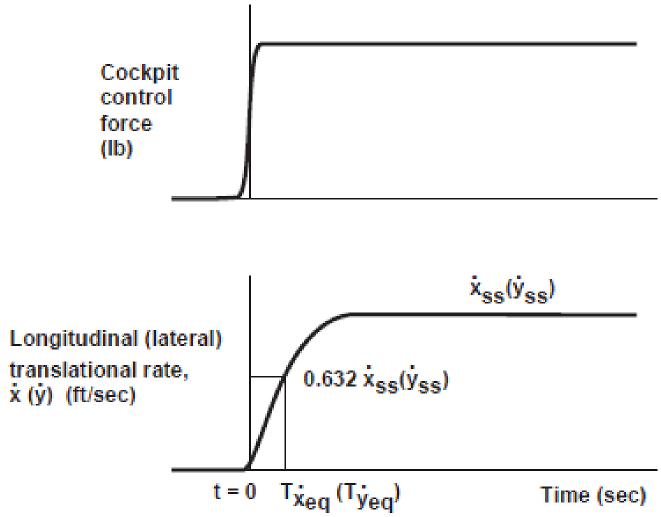


a) Requirement on dynamics of displayed torque based on step collective change

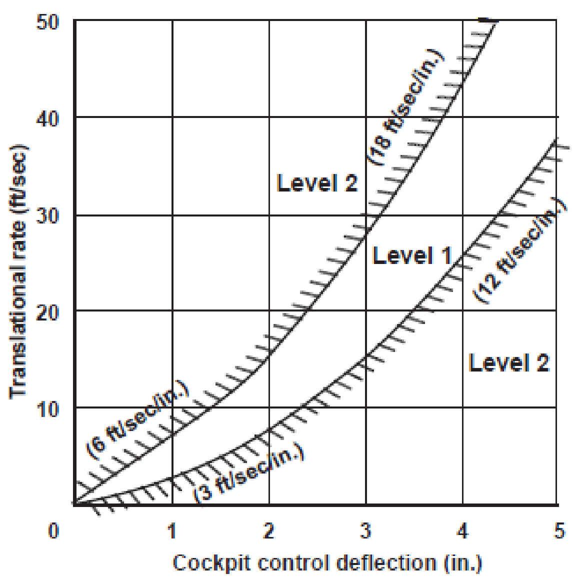


b) Definition of Q_0/Q_1 and t_p for displayed torque requirement

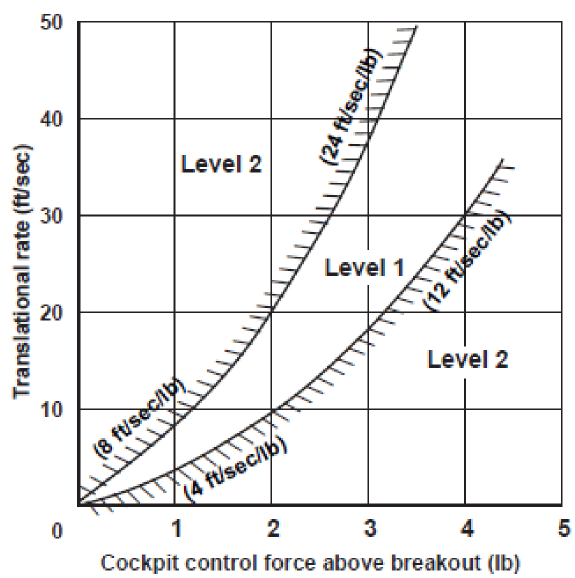
Figure 16. Displayed torque response requirement



a) Definition of equivalent rise time, $T_{\dot{x}_{eq}}$ ($T_{\dot{y}_{eq}}$)



b) Control/response requirement for centerstick controllers



c) Control/response requirement for sidestick controllers

Figure 17. Requirements for longitudinal (lateral) Translational Rate Response-Types – hover and low speed

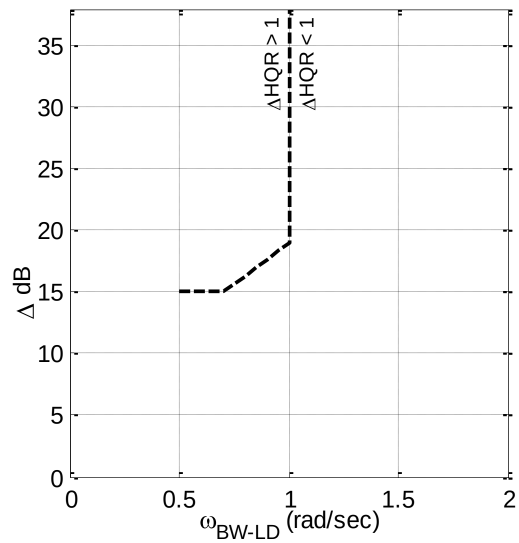


Figure 18. ΔHQR from baseline for externally slung loads

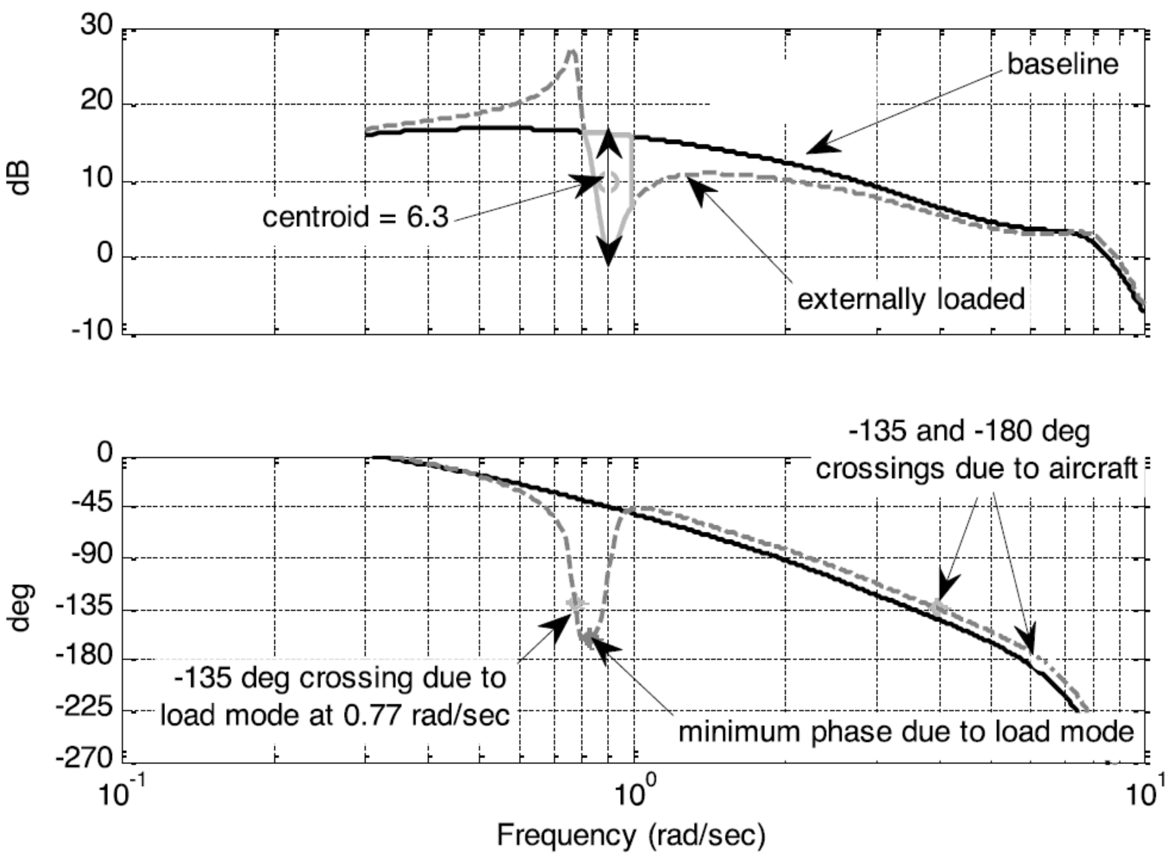
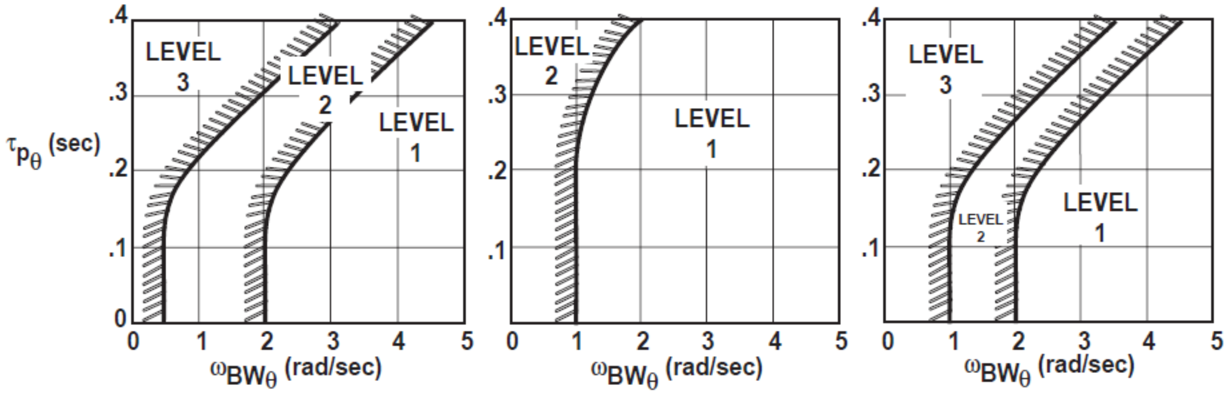


Figure 19. Externally slung load parameters

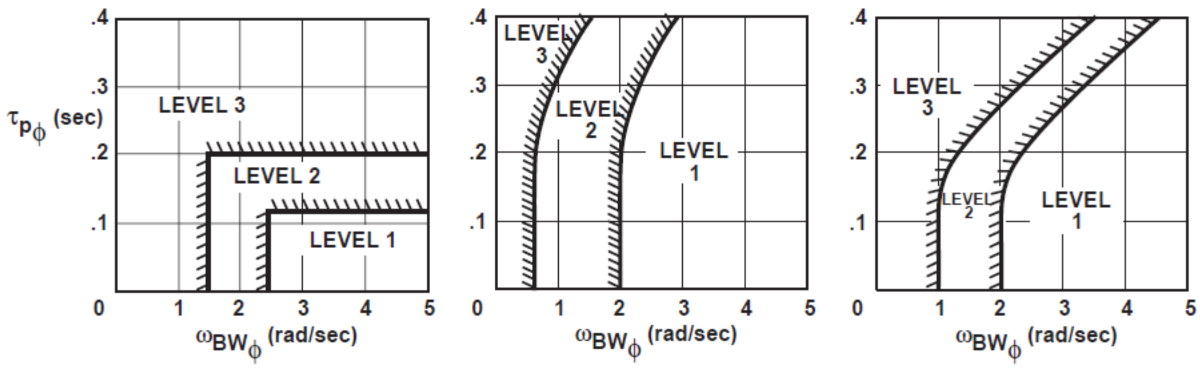


a) Target Acquisition and Tracking

b) All Other MTEs - VMC and Fully Attended Operations

c) All Other MTEs - IMC and/or Divided Attention Operations

Figure 20. Requirements for small-amplitude pitch attitude changes – forward flight

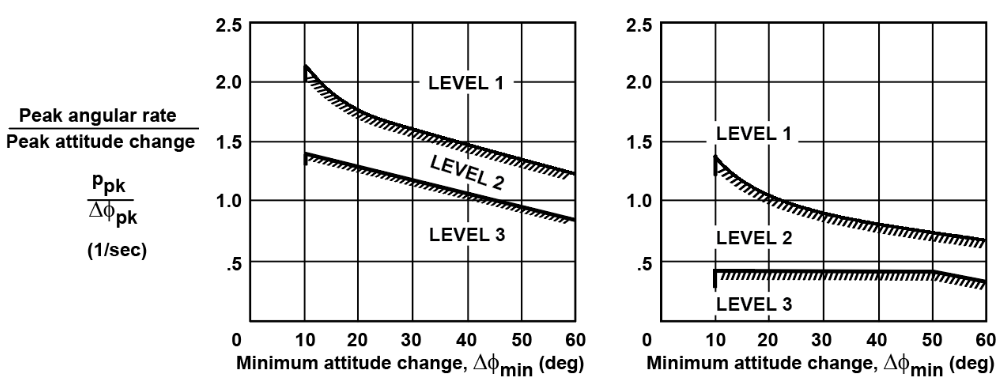


a) Target Acquisition and Tracking

b) All Other MTEs - VMC and Fully Attended Operations

c) All Other MTEs - IMC and/or Divided Attention Operations

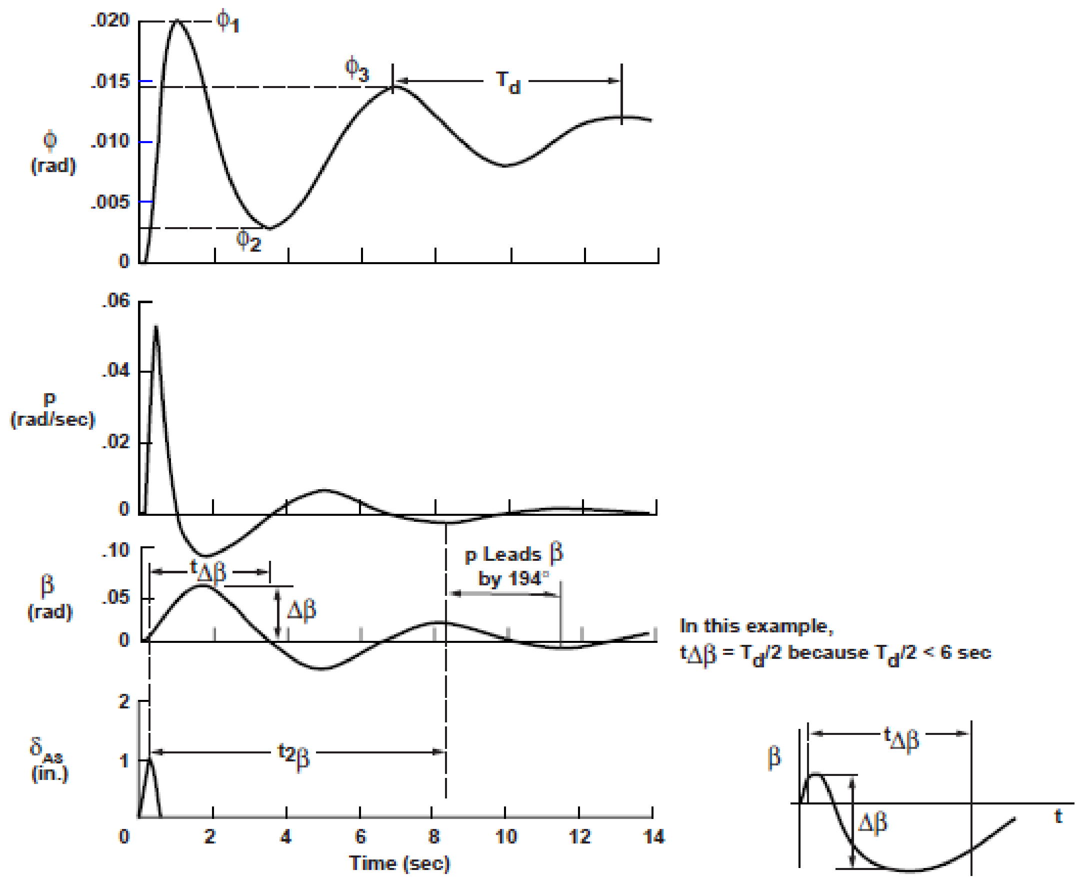
Figure 21. Requirements for small-amplitude roll attitude changes – forward flight



a) Target Acquisition and Tracking

b) All Other MTEs

Figure 22. Requirements for moderate-amplitude roll attitude changes – forward flight



Example to illustrate definition of $\Delta\beta$ in a response with sideslip reversal at $t < t_{\Delta\beta}$

$$T_d = \frac{2\pi}{\omega_n \sqrt{1-\zeta^2}}$$

ζ, ω_n from paragraph 3.4.9.1

$$\frac{\phi_{osc}}{\phi_{av}} = \frac{\phi_1 + \phi_3 - 2\phi_2}{\phi_1 + \phi_3 + 2\phi_2} \quad (\zeta \le 0.2) \qquad = \frac{\phi_1 - \phi_2}{\phi_1 + \phi_2} \quad (\zeta > 0.2)$$

ϕ, β, δ_{AS} change in roll attitude, sideslip, and lateral control position from trim.

$\Delta\beta$ the maximum change in sideslip following an abrupt roll control pulse command within time $t_{\Delta\beta}$

$t_{\Delta\beta}$ the lesser of 6 sec or $T_d/2$.

$t_{n\beta}$ time for the lateral-directional oscillations in the sideslip response to reach the n[th] local maximum for a right command.

Ψ_β phase angle expressed as a lag for a cosine representation of the lateral-directional oscillation in sideslip, where:

$\Psi_\beta = -360\, t_{n\beta} / T_d + (n-1)\, 360$ (degrees) with n as in $t_{n\beta}$ above

$|\phi/\beta|_d$ at any instant, the ratio of amplitudes of the bank angle and sideslip angle envelopes in the lateral-directional oscillatory mode.

Figure 23. Roll-sideslip coupling parameters

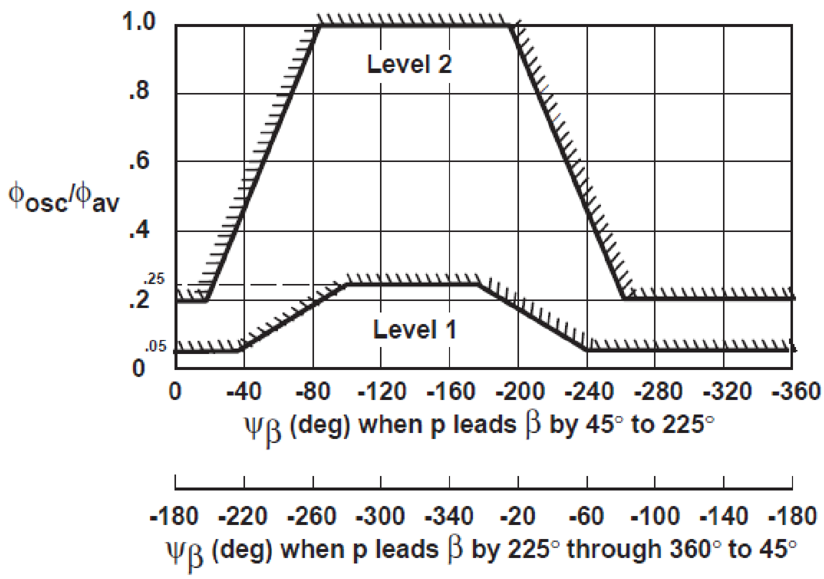


Figure 24. Bank angle oscillation limitations

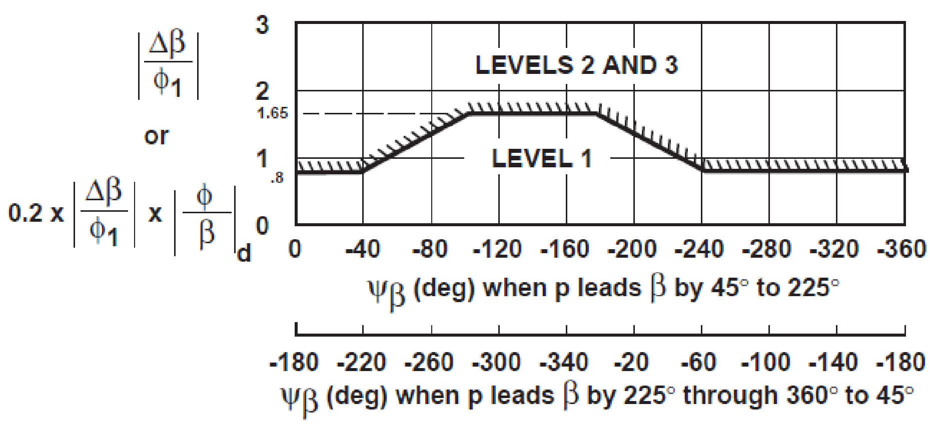


Figure 25. Sideslip excursion limitations

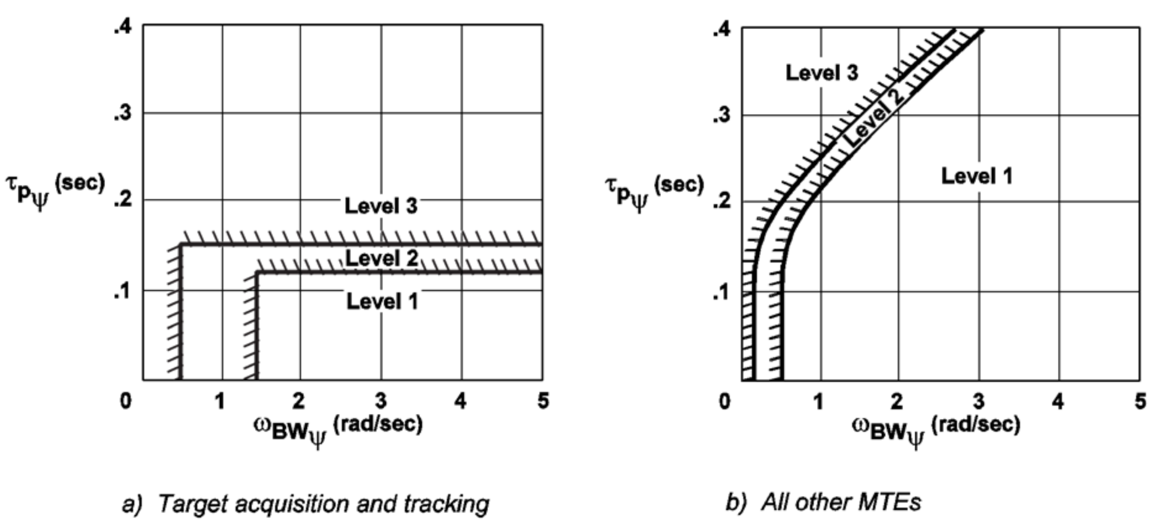


Figure 26. Requirement for small-amplitude yaw response – forward flight

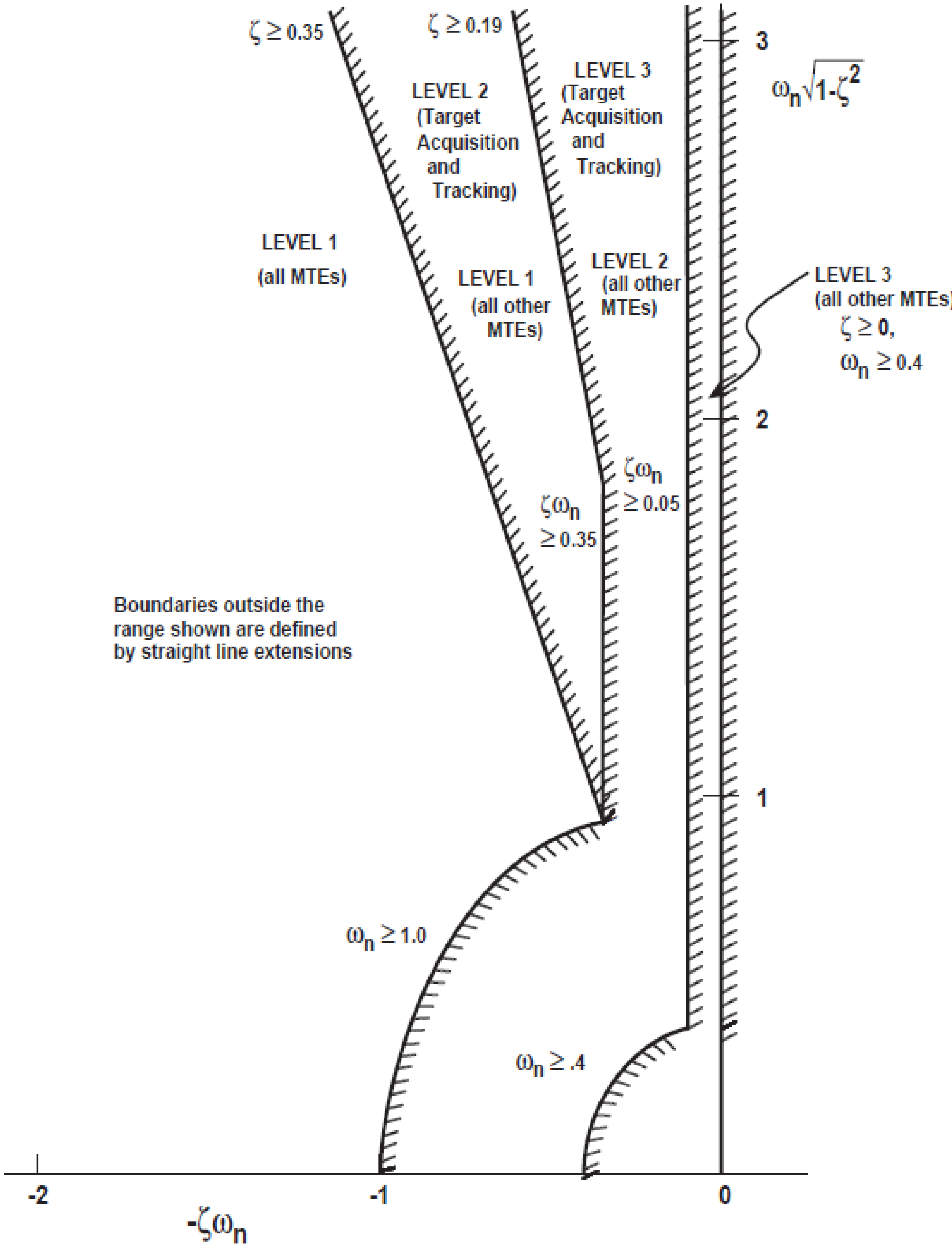
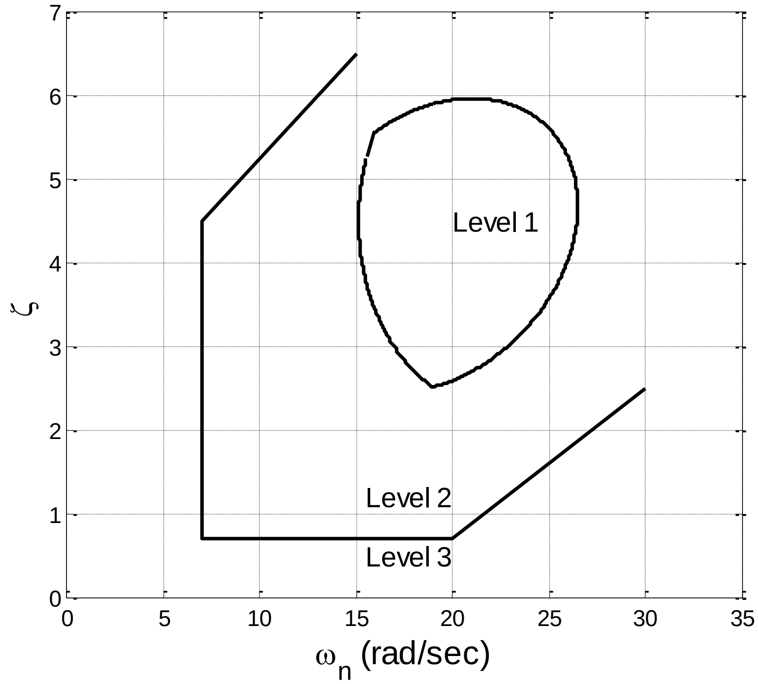
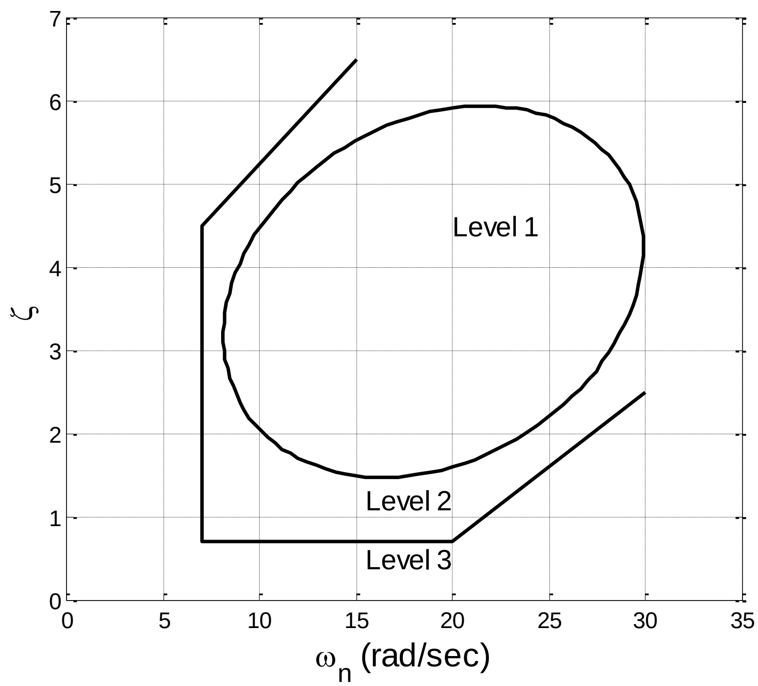


Figure 27. Lateral-directional oscillatory requirements



a) Rate command



b) Attitude command

Figure 28. Requirements for active inceptor cyclic dynamic characteristics

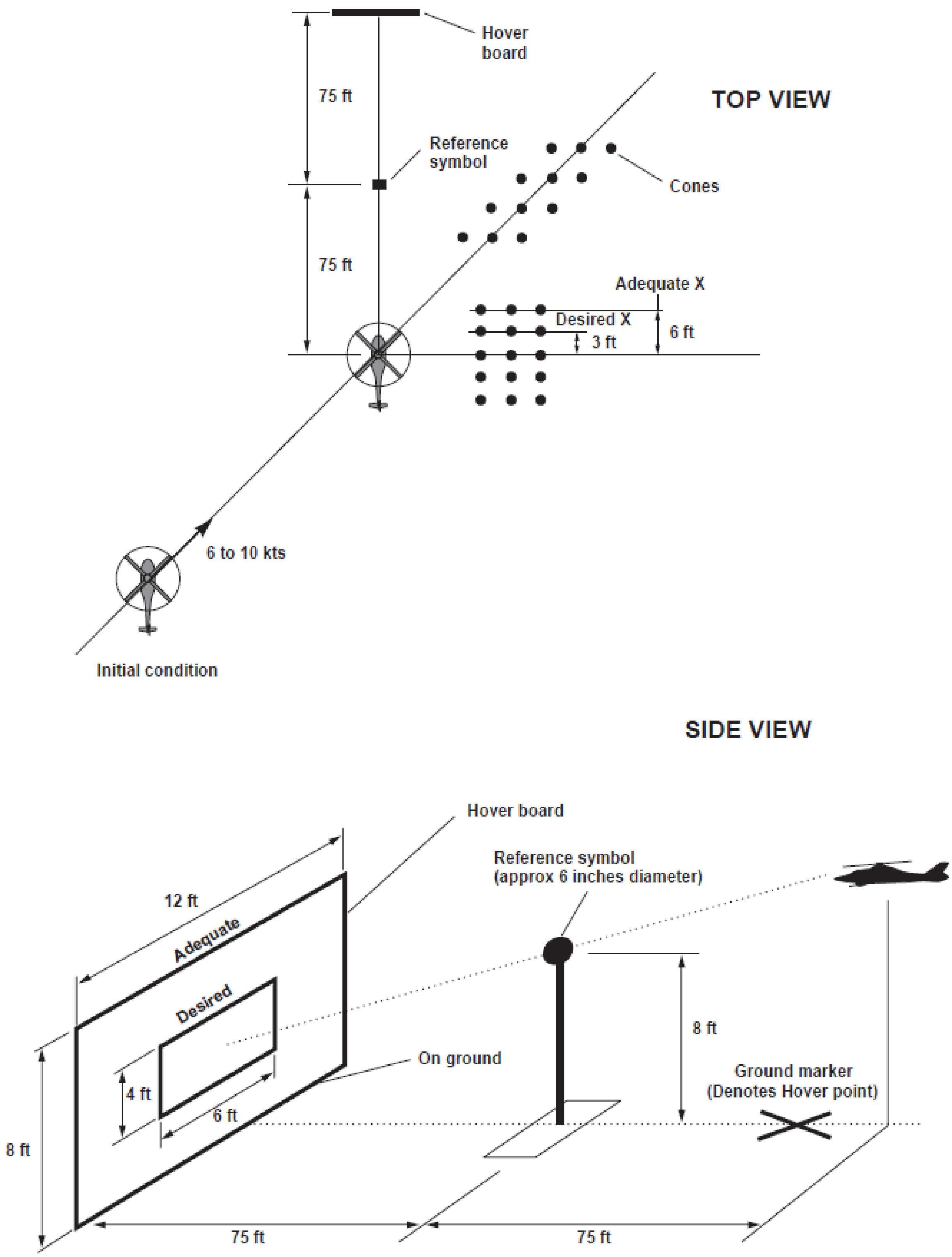


Figure 29. Suggested course for hover maneuver

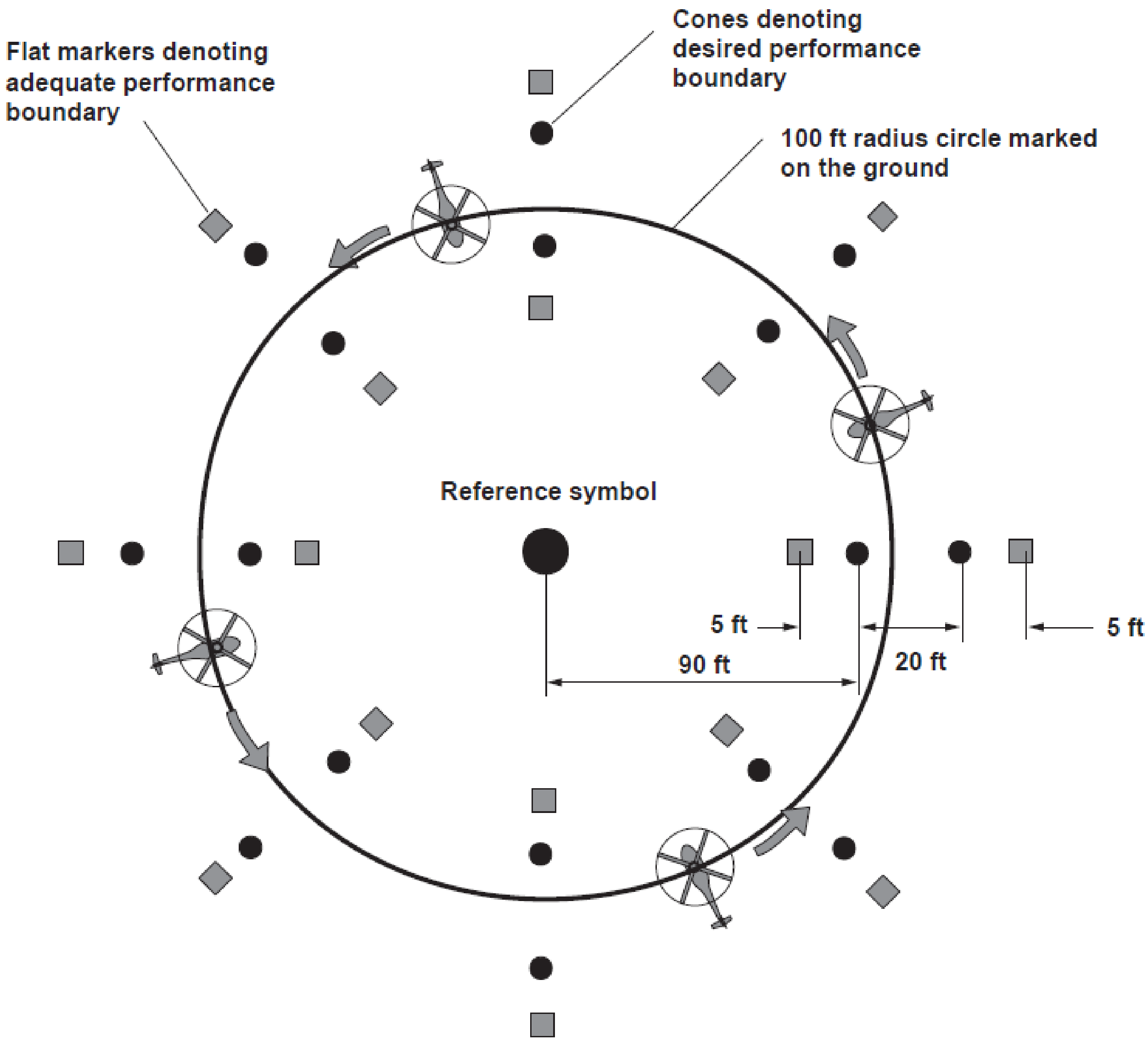


Figure 30. Suggested course for pirouette maneuver

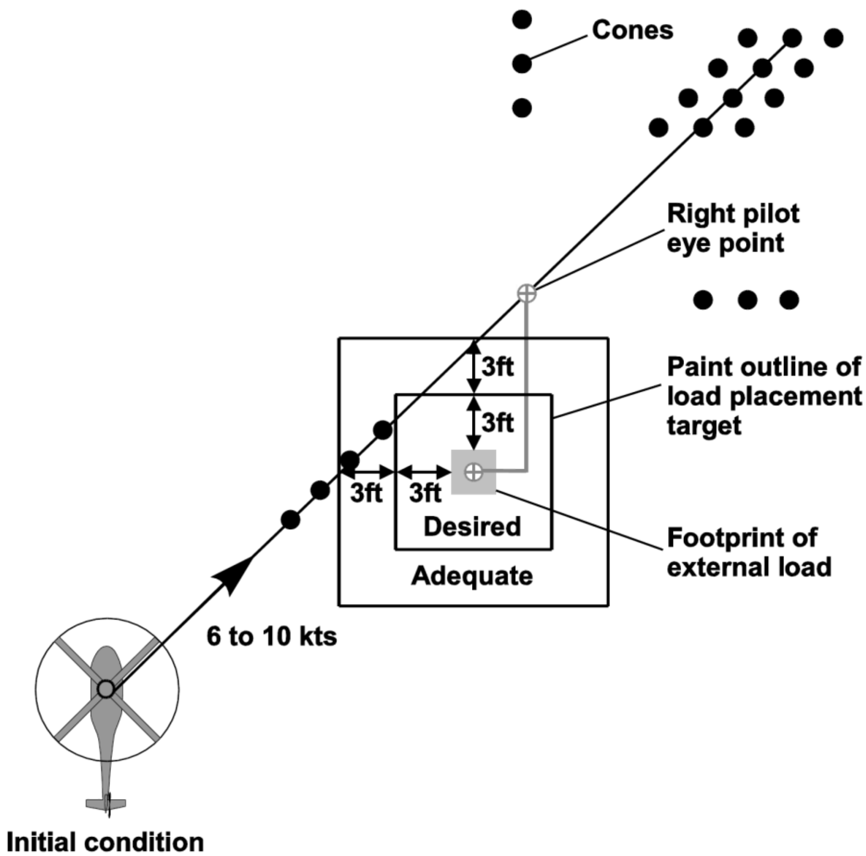


Figure 31. Load placement Mission Task Element (MTE) course

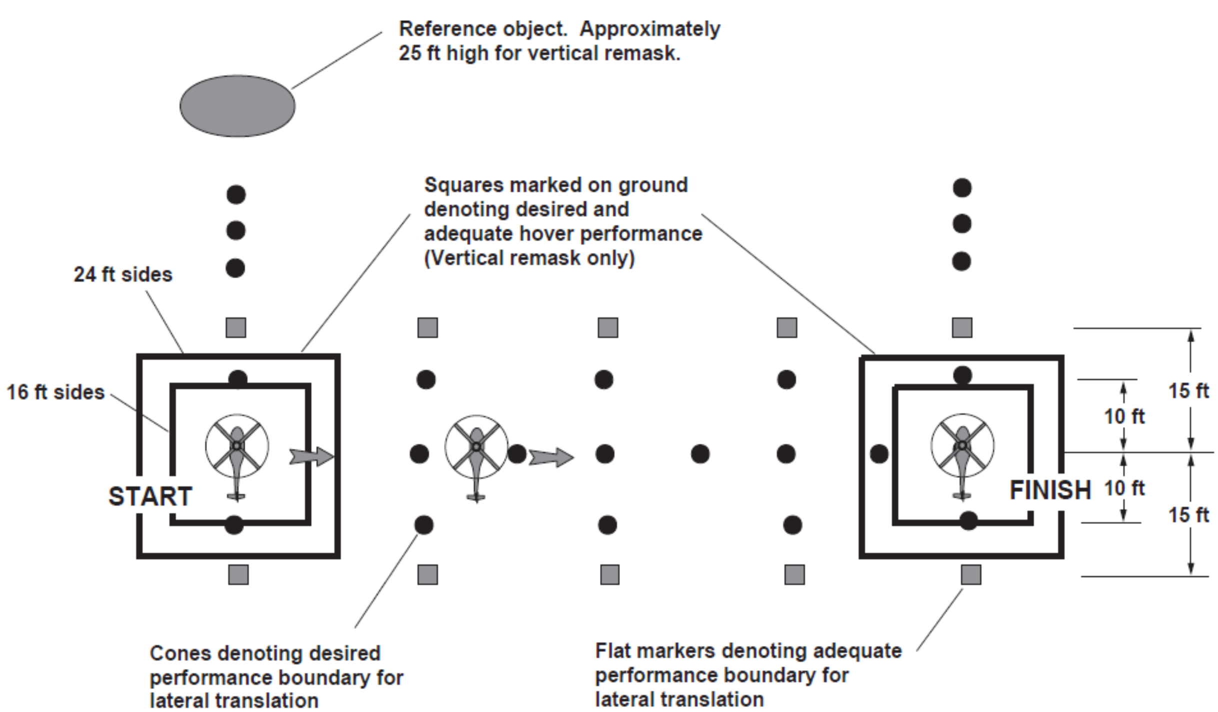


Figure 32. Suggested course for sidestep, lateral reposition, and vertical remask maneuvers

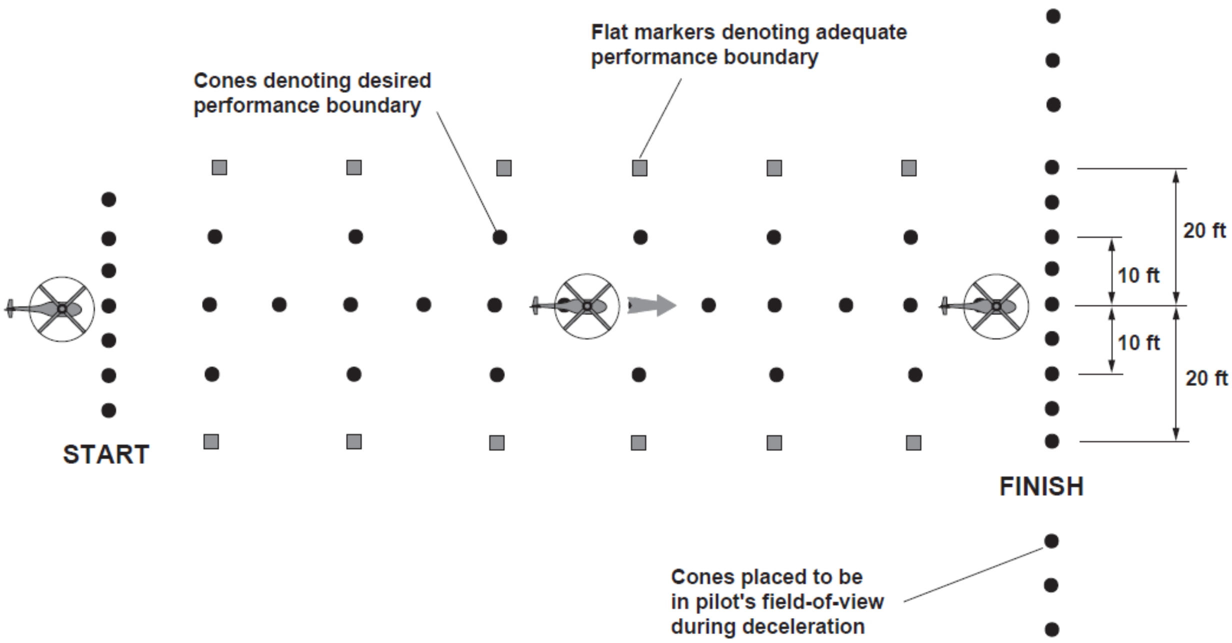


Figure 33. Suggested course for acceleration-deceleration maneuver

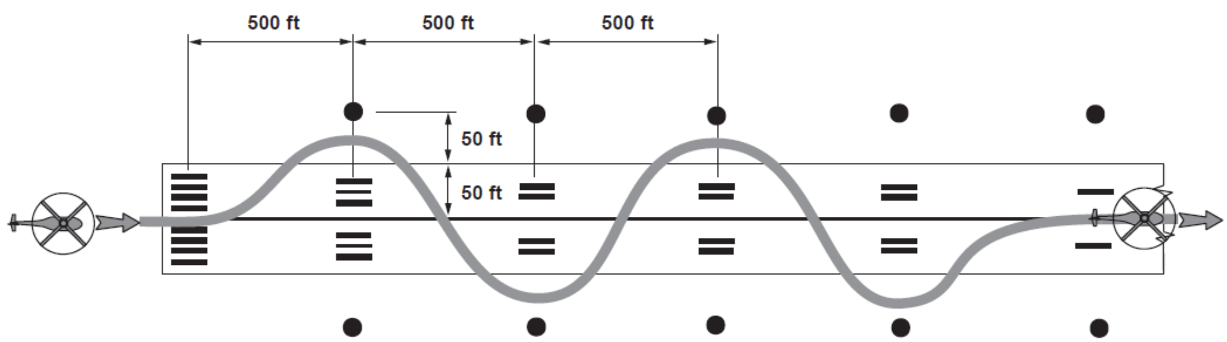


Figure 34. Suggested course for slalom maneuver